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Singh et al.

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(54) **EXTERNAL FIXATOR SYSTEM**

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(73) Assignee: **Stryker Trauma SA** (CH)

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Related U.S. Application Data

(63) Continuation of application No. 13/792,634, filed on Mar. 11, 2013, now Pat. No. 8,945,128, which is a continuation-in-part of application No. 13/206,058, filed on Aug. 9, 2011, now Pat. No. 8,834,467.

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A61B 17/66 (2006.01)
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CPC ***A61B 17/62*** (2013.01); ***A61B 17/645*** (2013.01); ***A61B 17/66*** (2013.01); *A61B 17/8875* (2013.01)

(58) **Field of Classification Search**
CPC A61B 17/62; A61B 17/645; A61B 17/66
USPC 606/54–59
See application file for complete search history.

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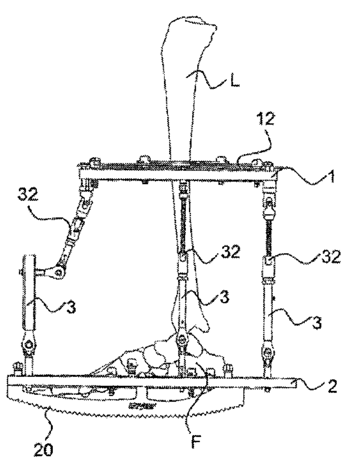
(57) **ABSTRACT**

An external fixation frame for correcting a bone deformity includes a first fixation ring and a second fixation ring. A posterior adjustable length strut couples a posterior portion of the first fixation ring to a posterior portion of the second fixation ring and has universal joint. Medial and lateral adjustable length struts couples medial and lateral portions of the first fixation ring to medial and lateral portions of the second fixation ring respectively, each of the medial and lateral adjustable length struts including a constrained hinge joint. The fixation frame also includes a half ring hingedly coupled to the second fixation ring, and an anterior adjustable length strut coupling an anterior portion of the first fixation ring to the half ring.

19 Claims, 29 Drawing Sheets



(51) **Int. Cl.**

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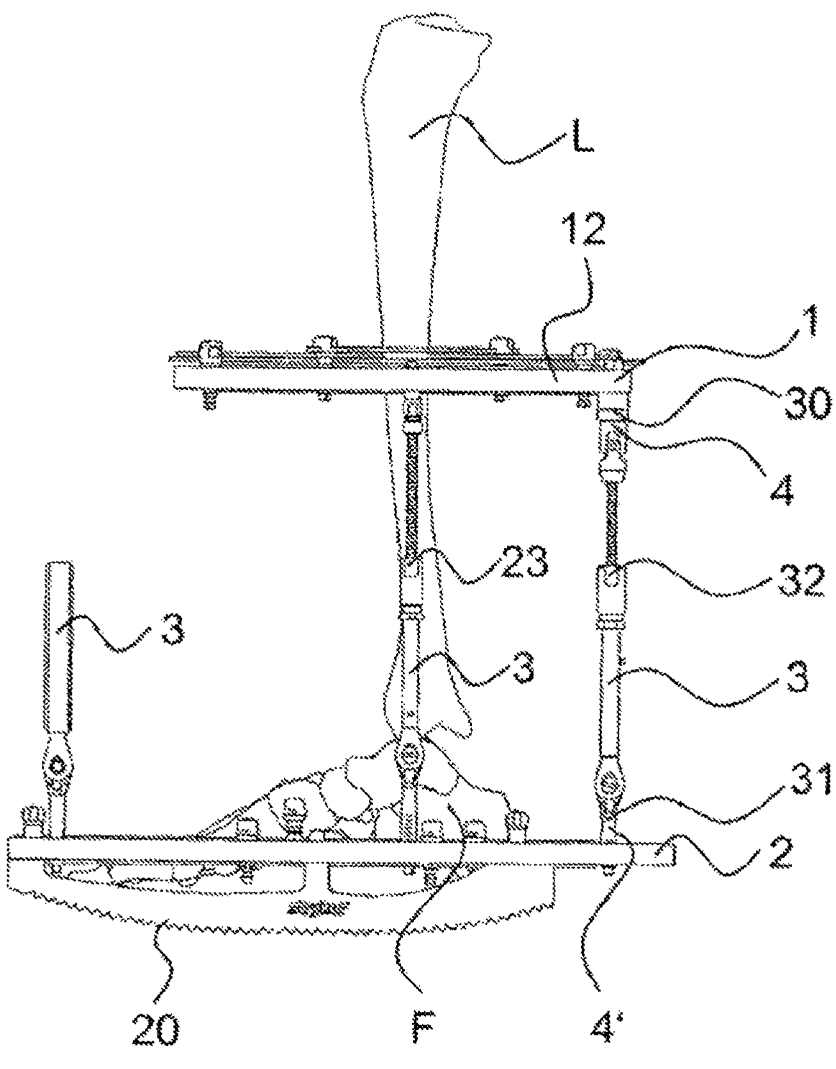


FIG. 1A

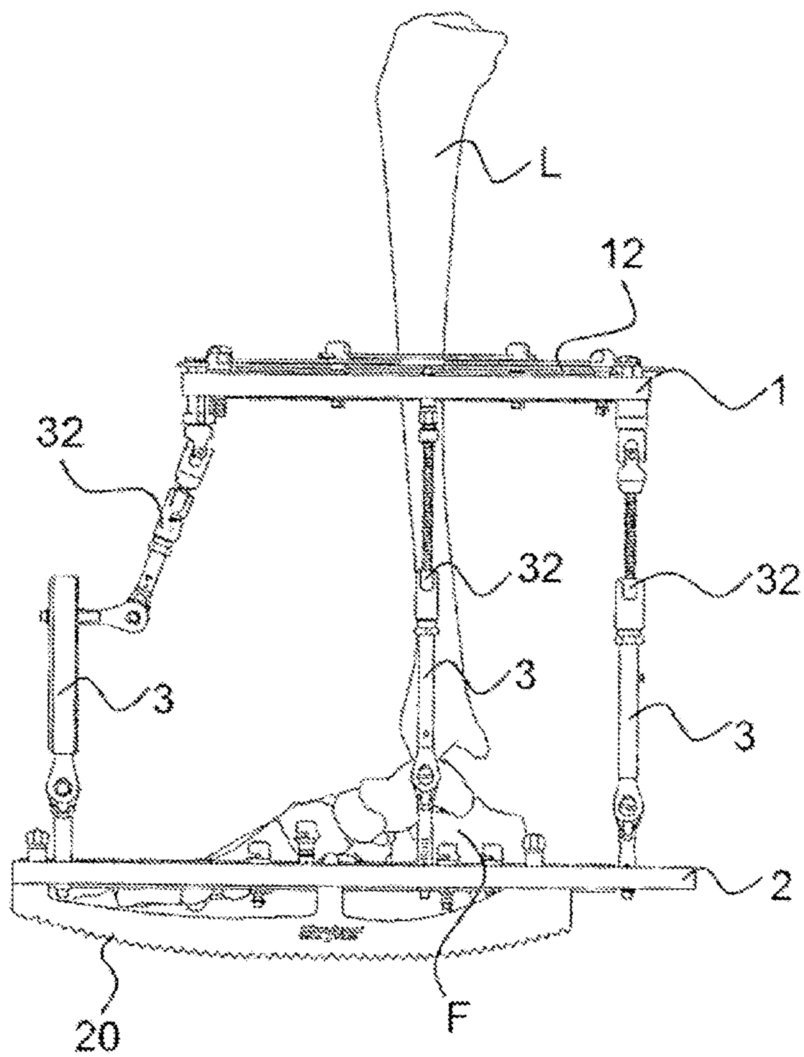
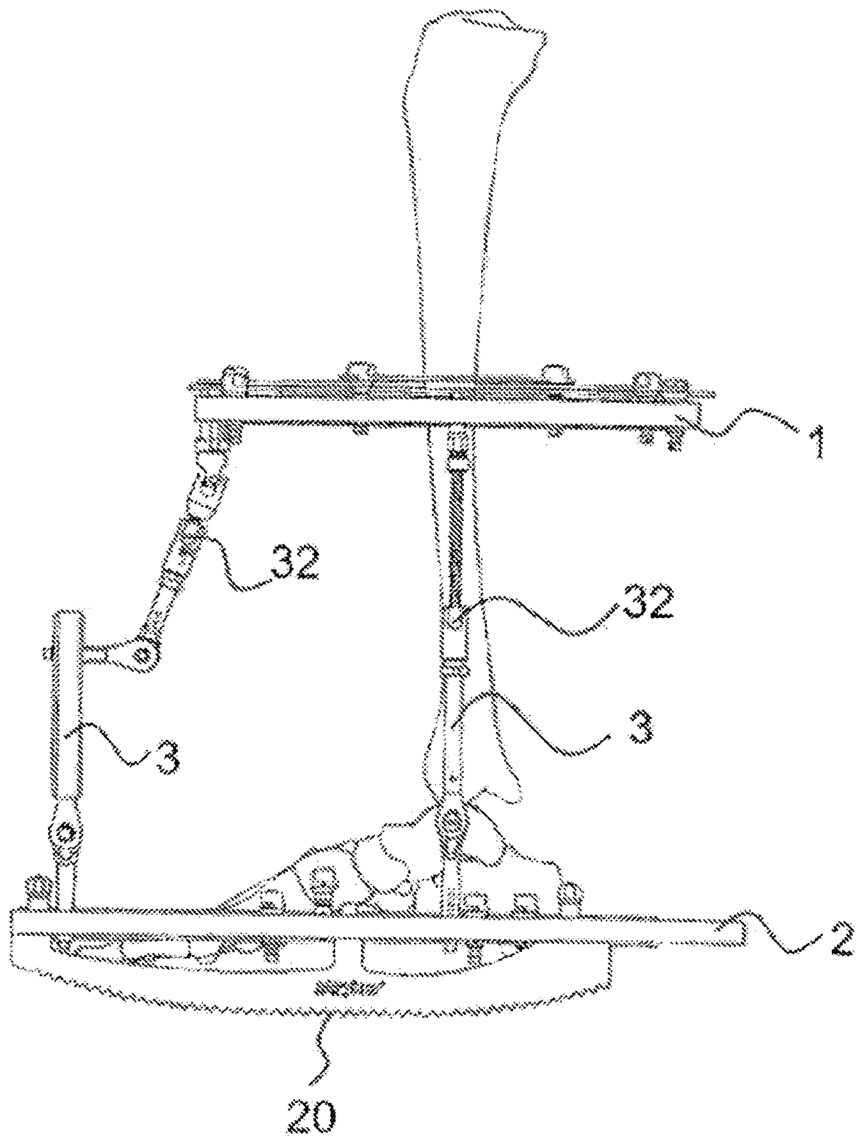


FIG. 1B



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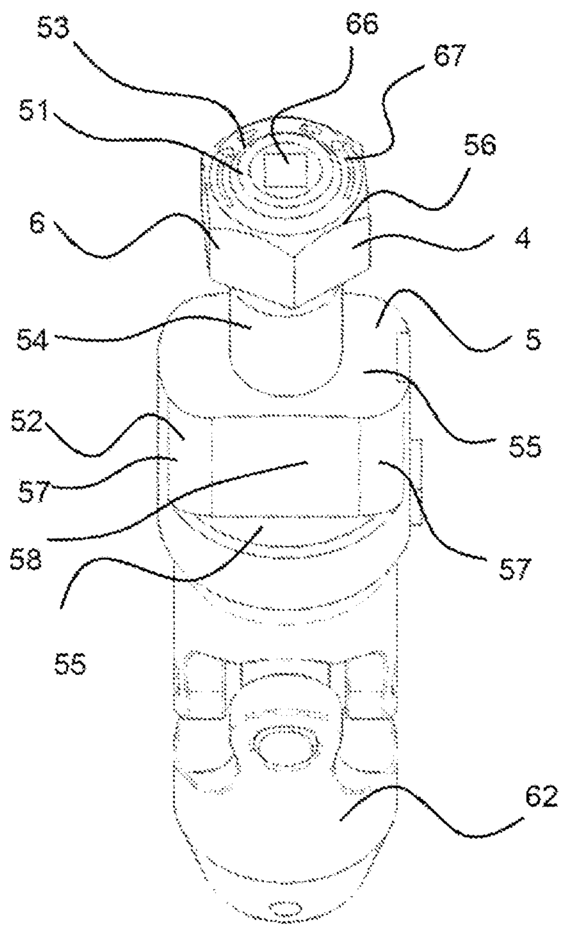

FIG. 2

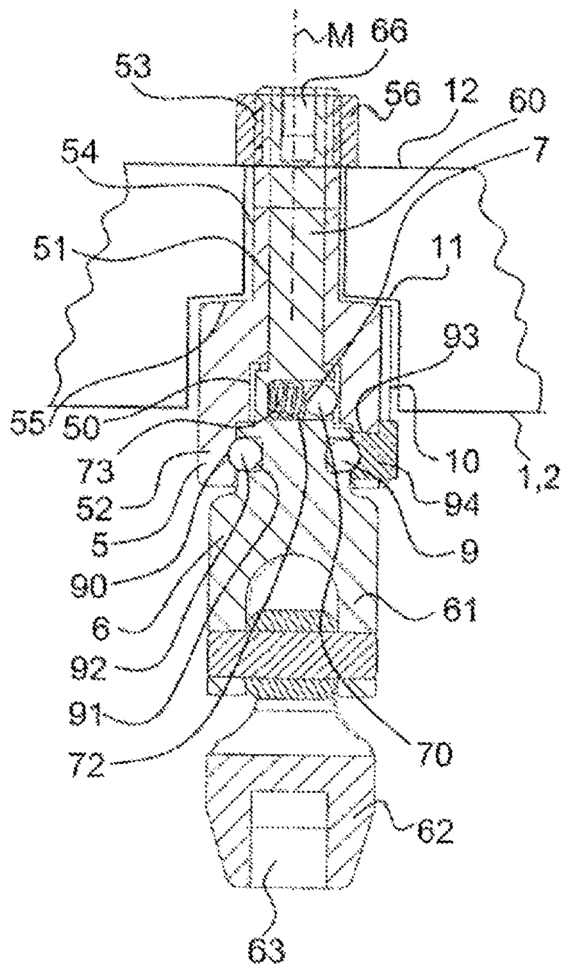
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FIG. 3

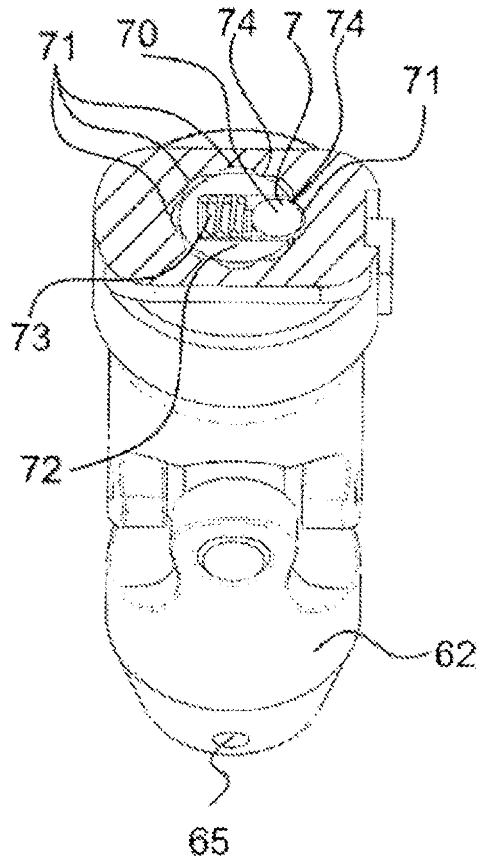

FIG. 4

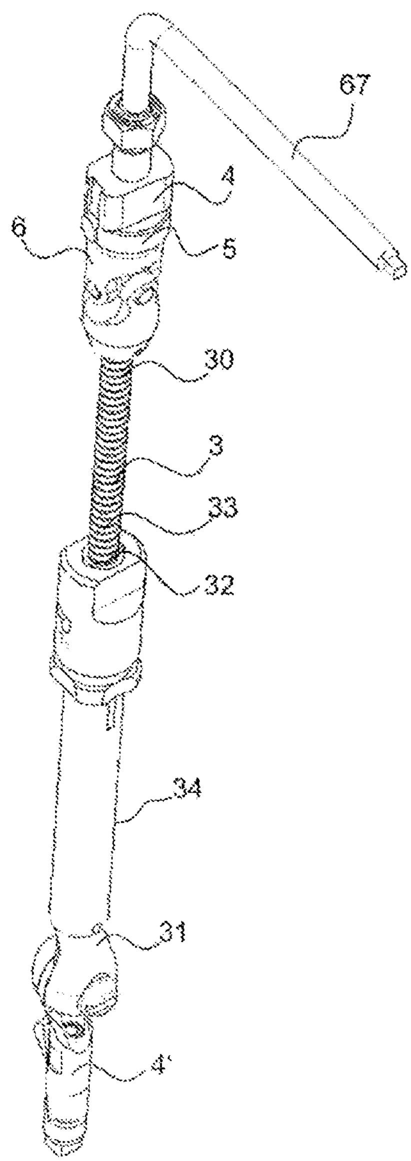

FIG. 5

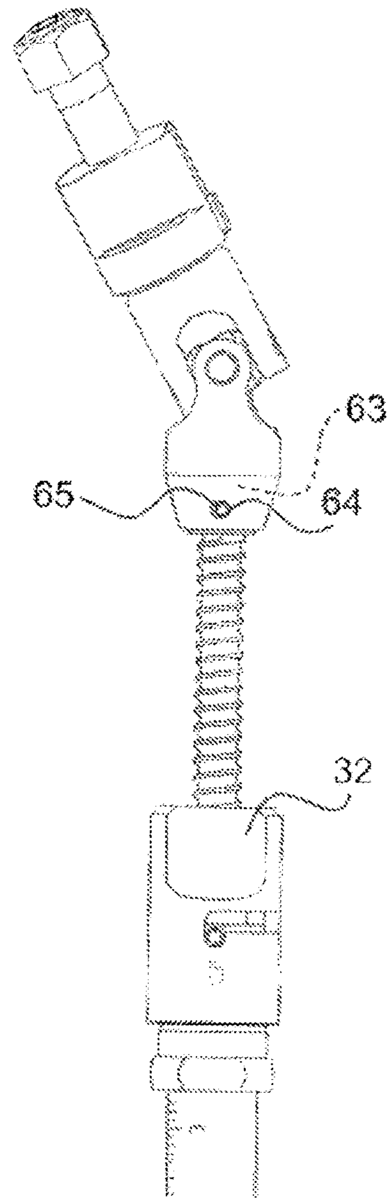

FIG. 6

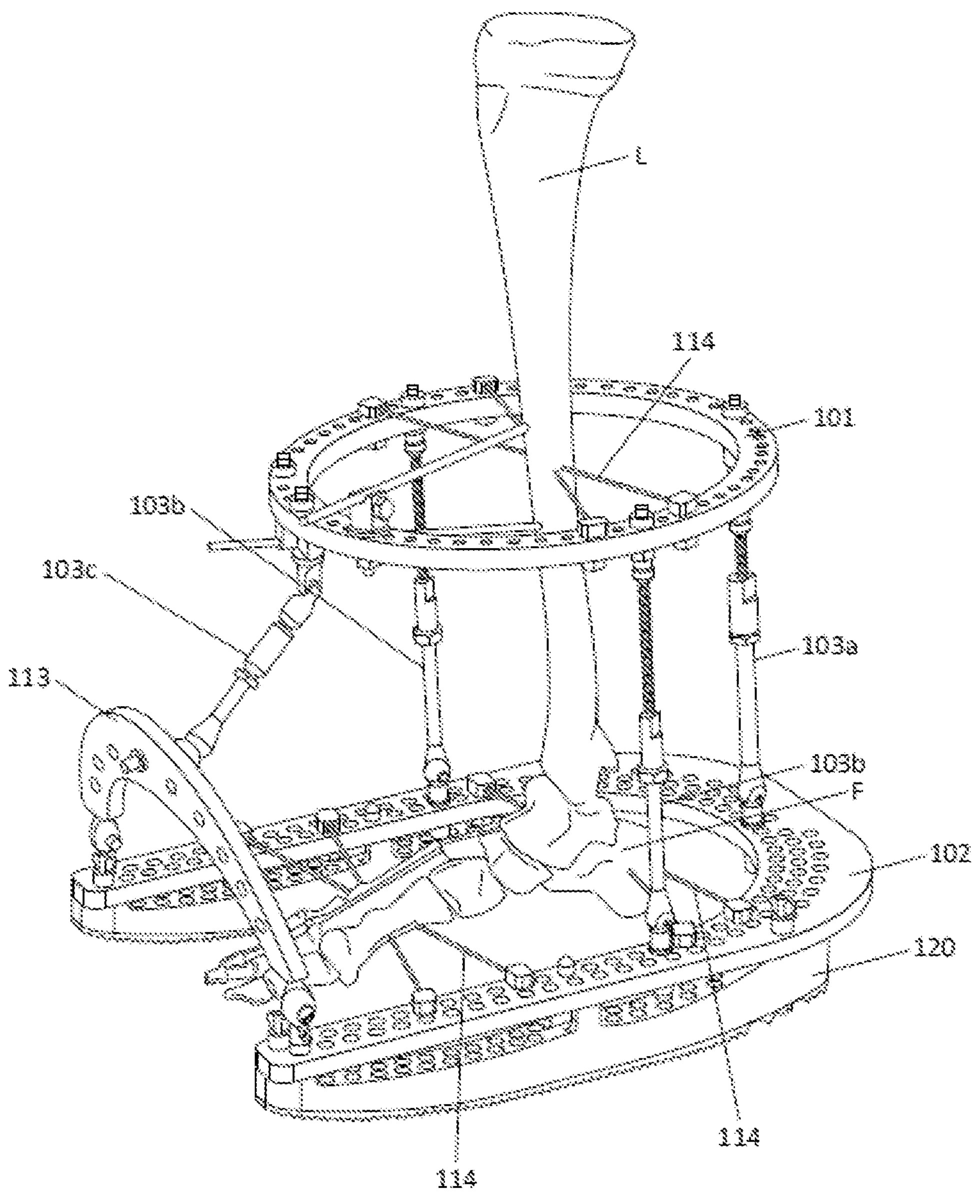

FIG. 7

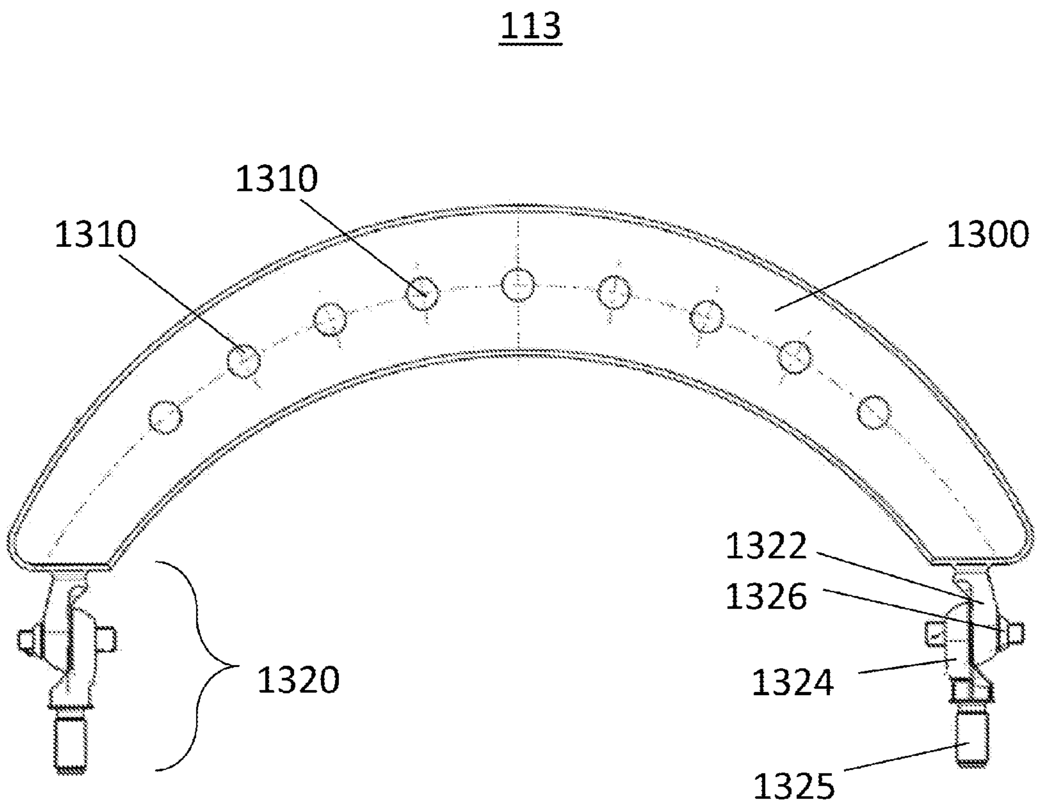

FIG. 8A

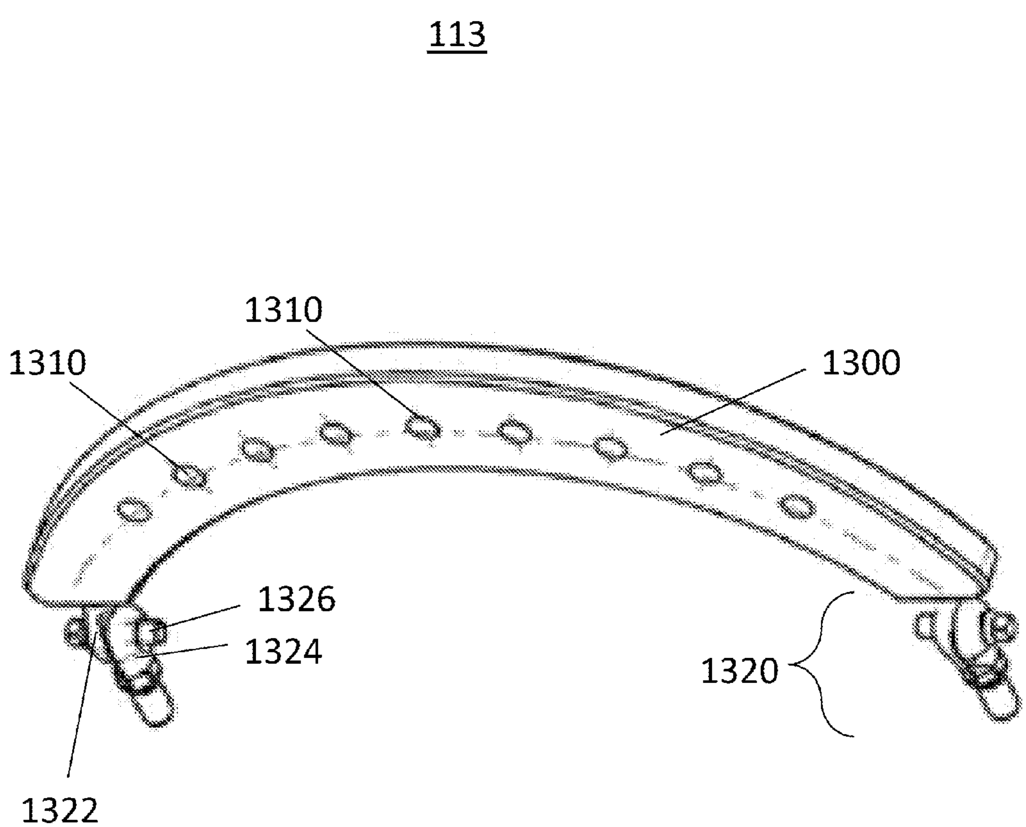

FIG. 8B

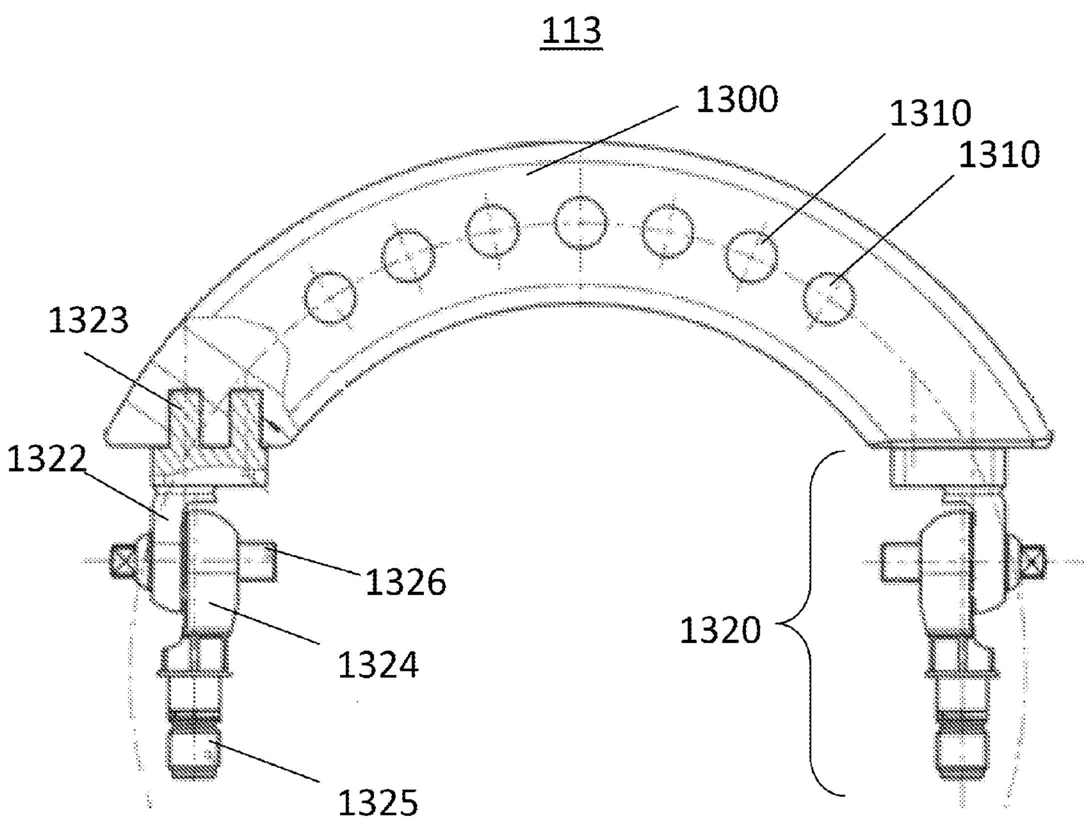

FIG. 8C

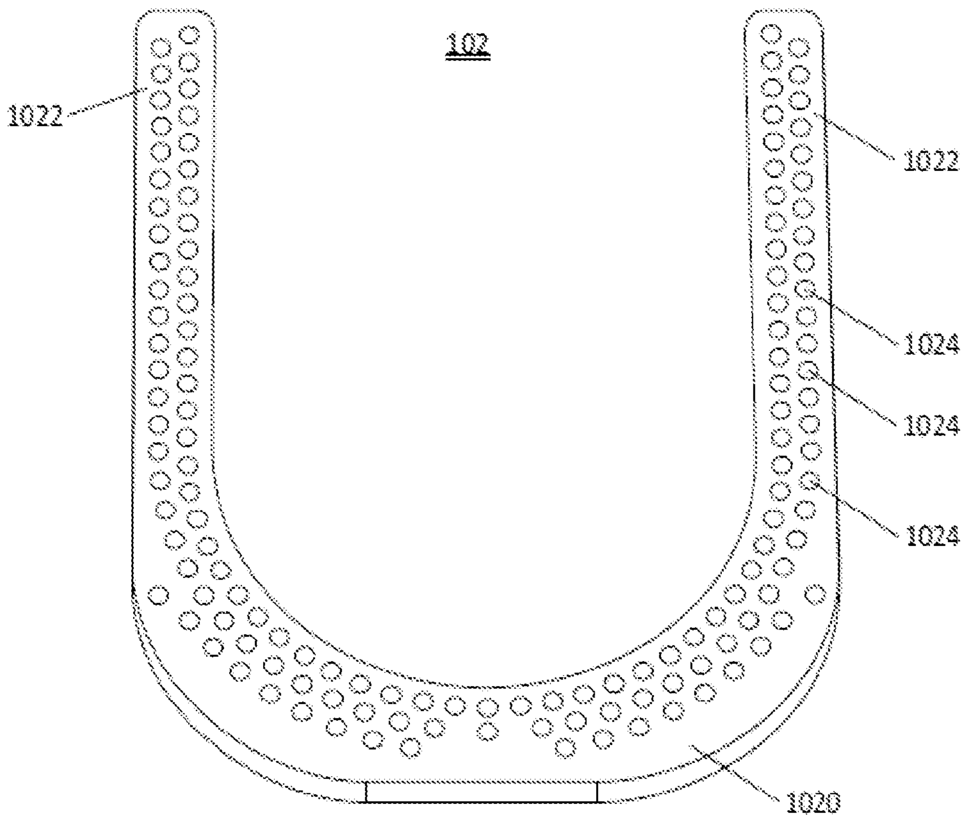

FIG. 9A

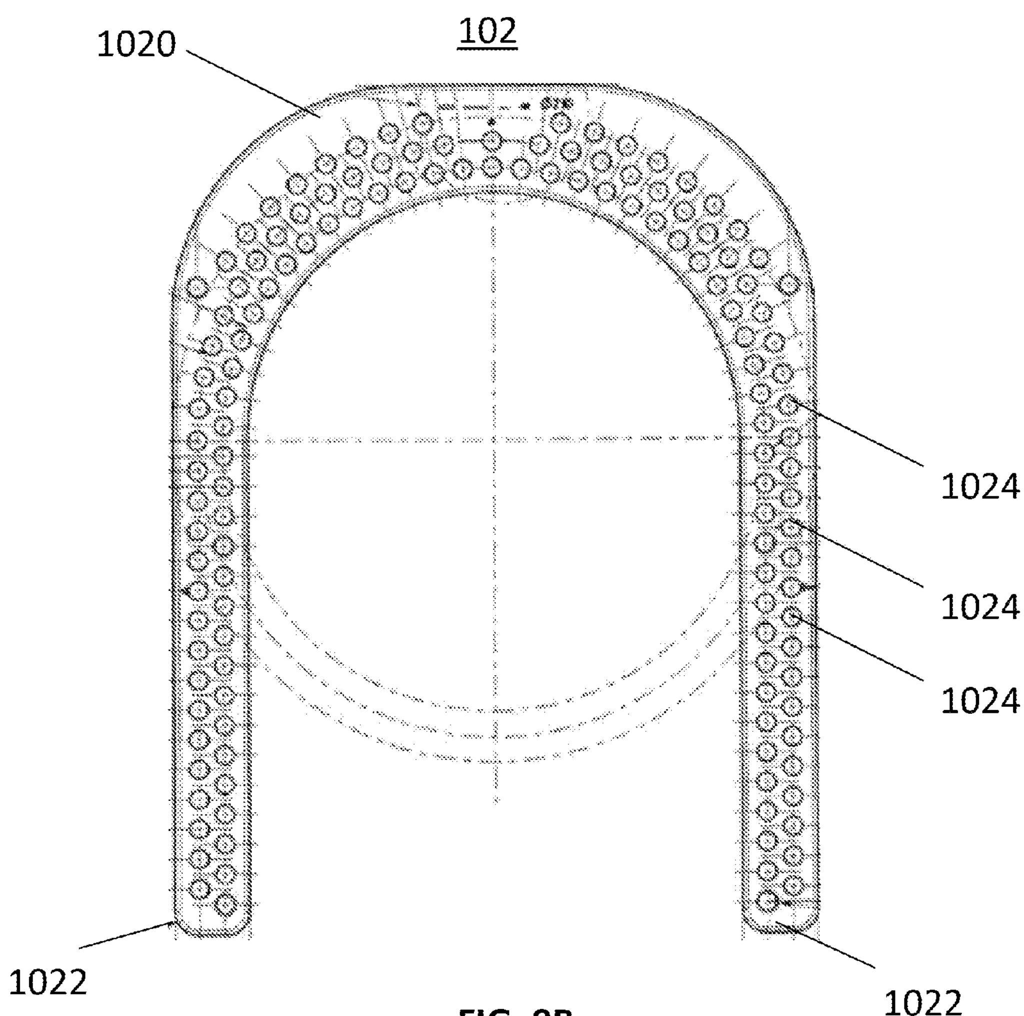

FIG. 9B

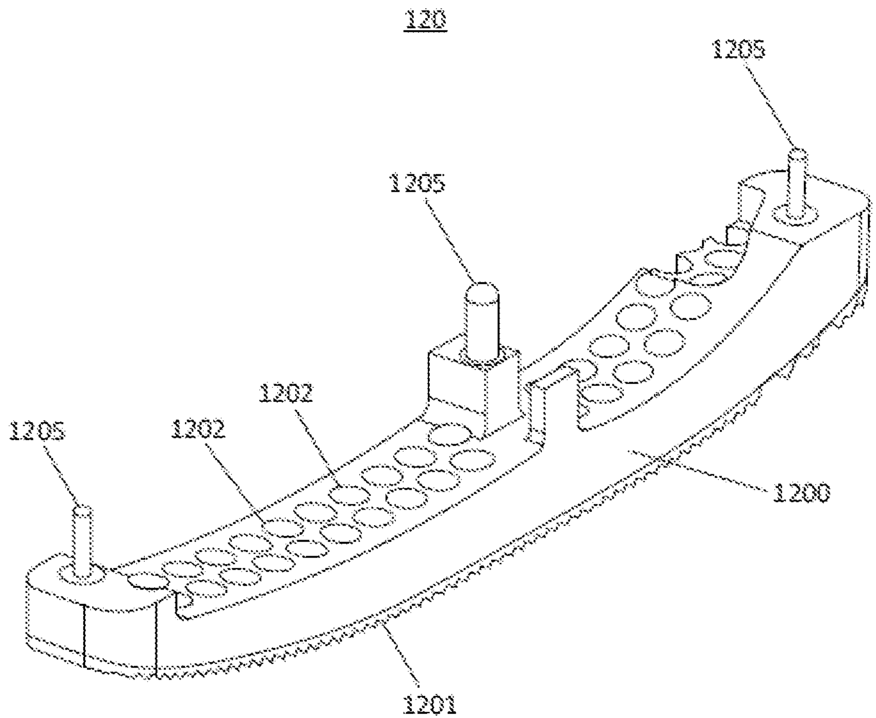

FIG. 10A

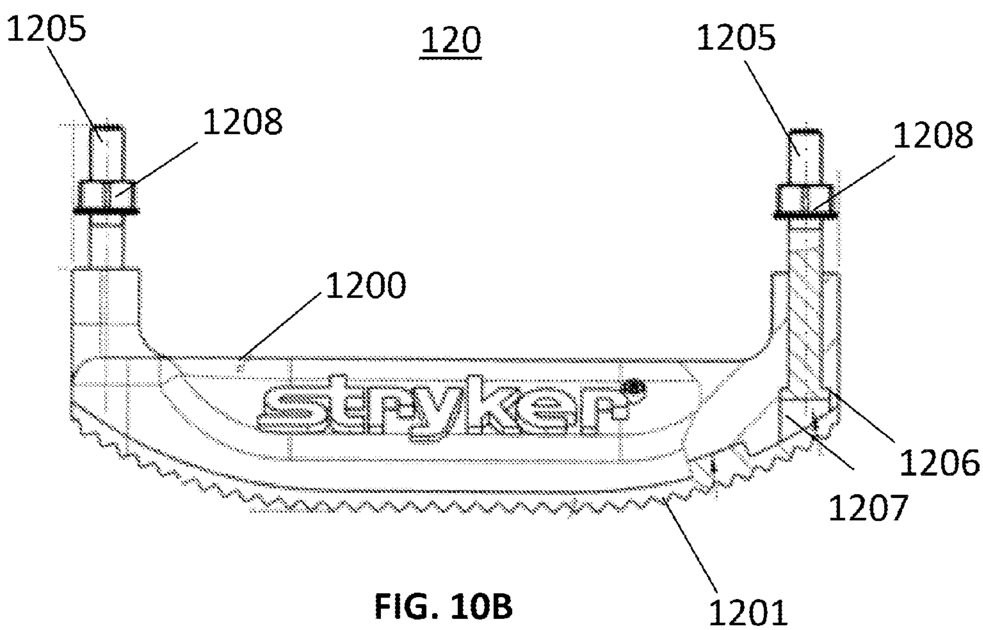

FIG. 10B

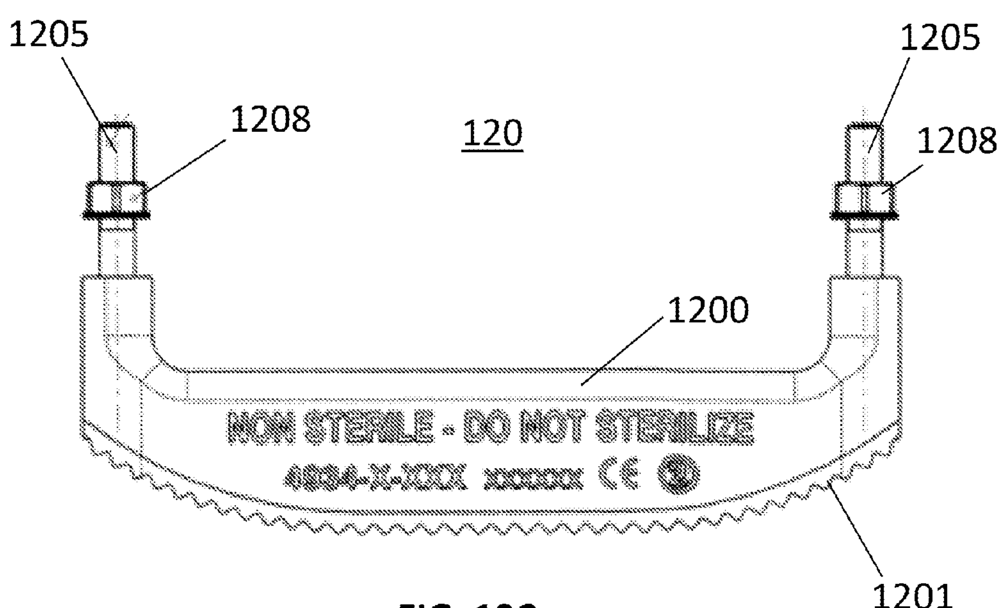

FIG. 10C

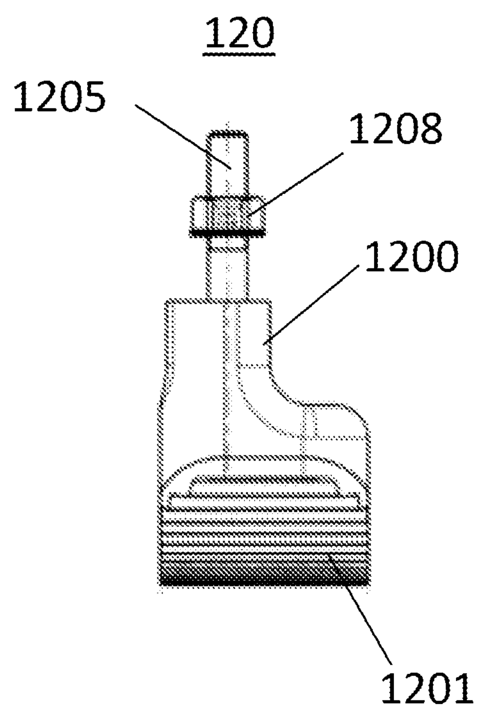

FIG. 10D

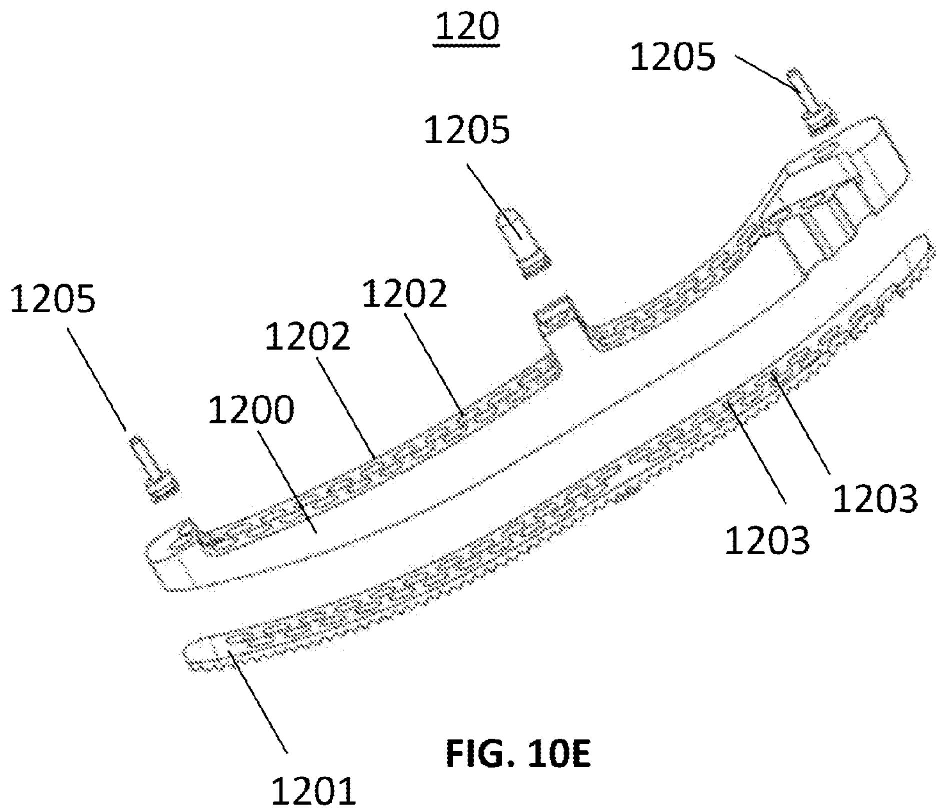

FIG. 10E

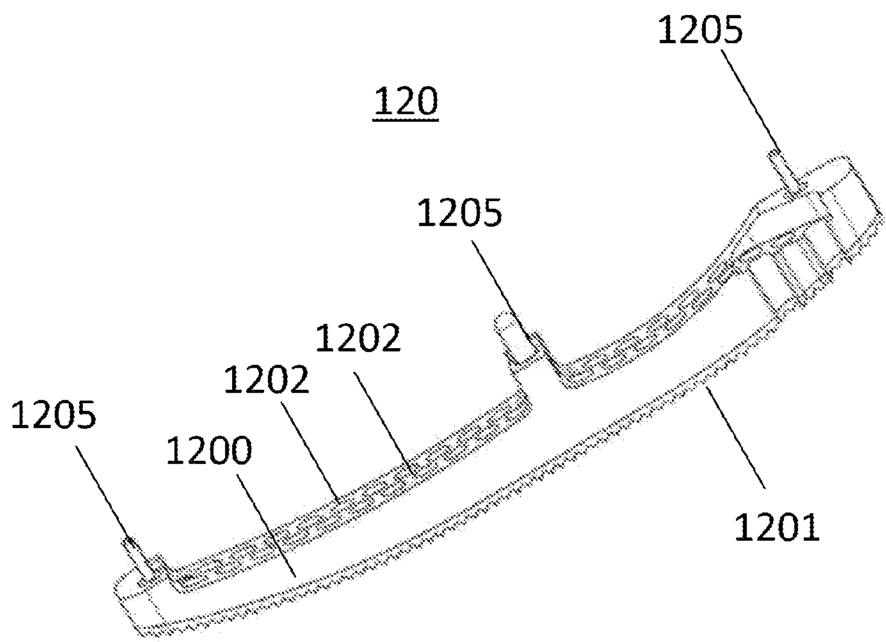

FIG. 10F

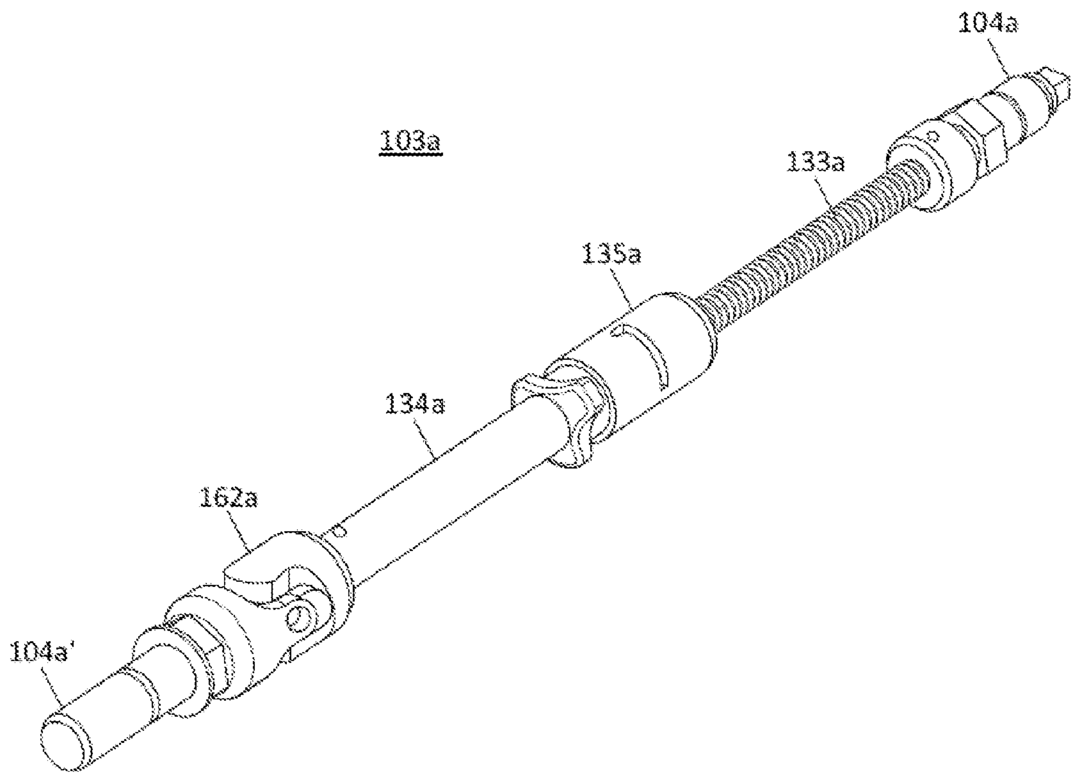

FIG. 11A

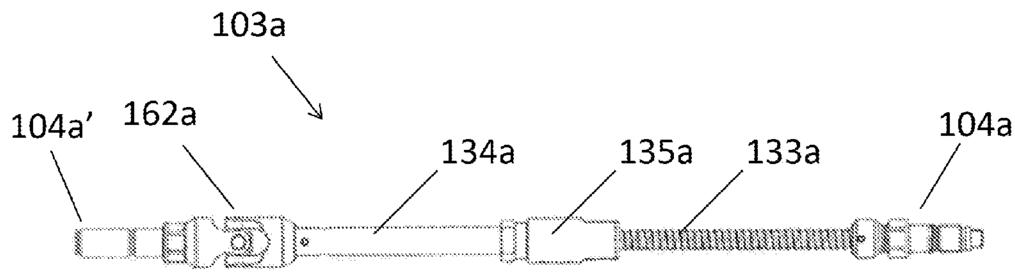

FIG. 11B

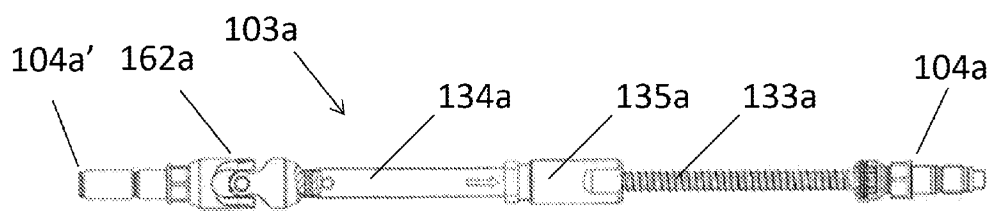

FIG. 11C

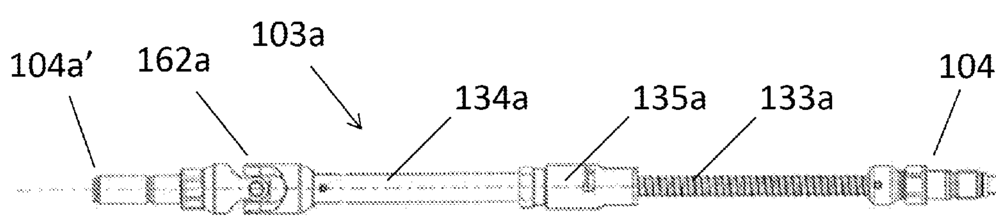

FIG. 11D

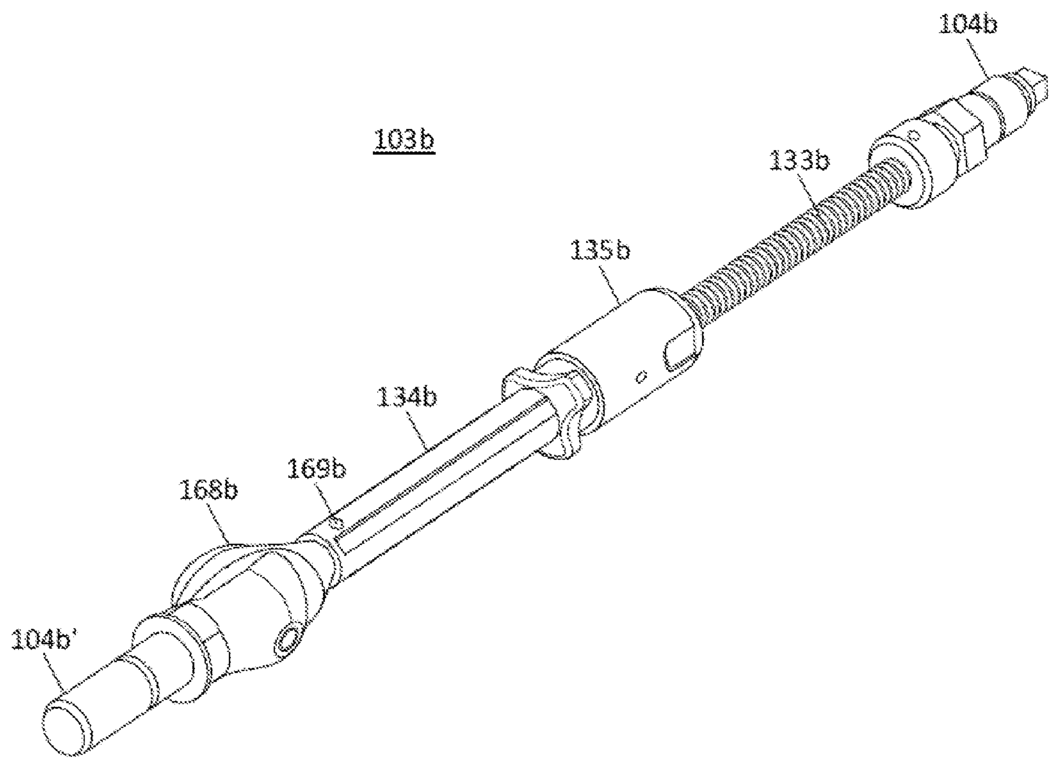

FIG. 12A

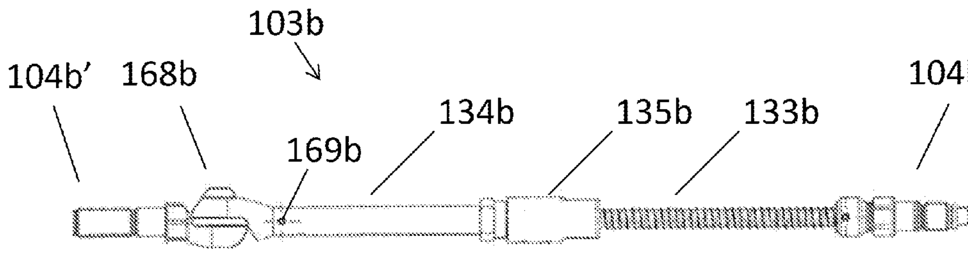

FIG. 12B

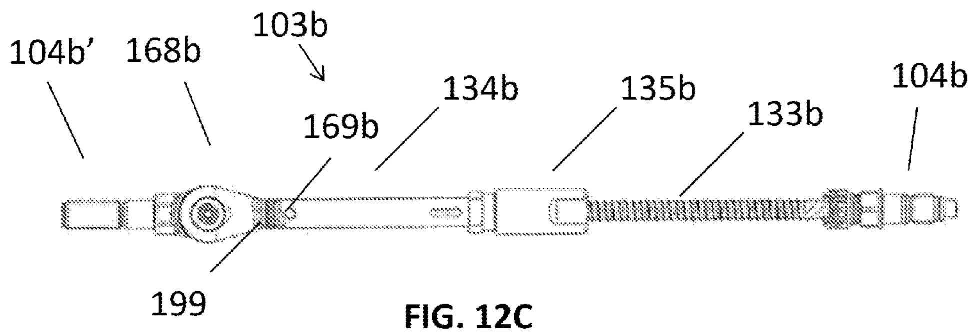

FIG. 12C

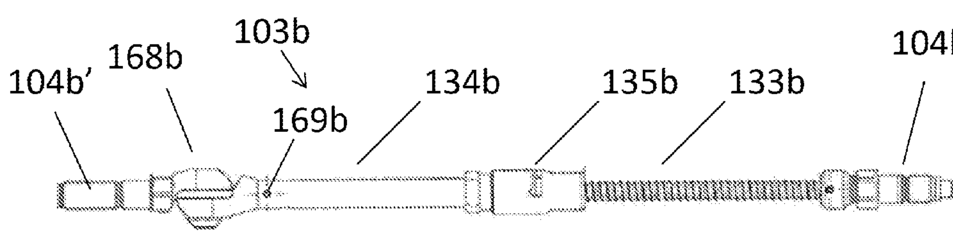

FIG. 12D

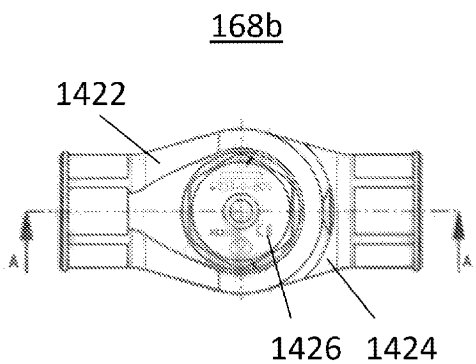

FIG. 13A

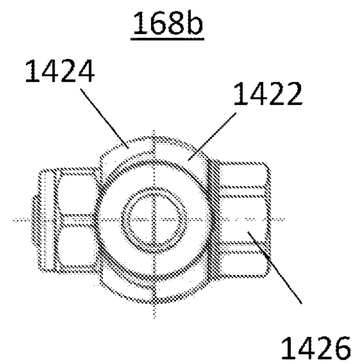

FIG. 13B

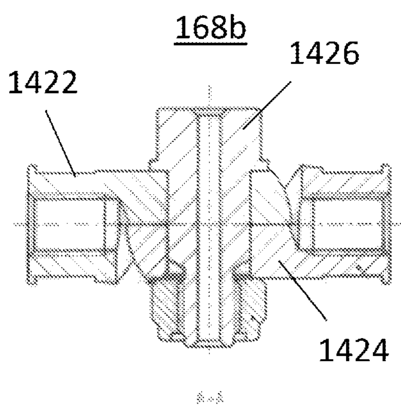

FIG. 13C

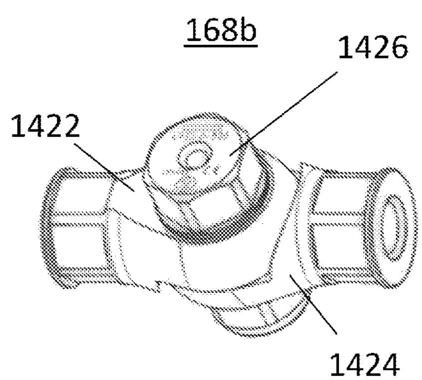

FIG. 13D

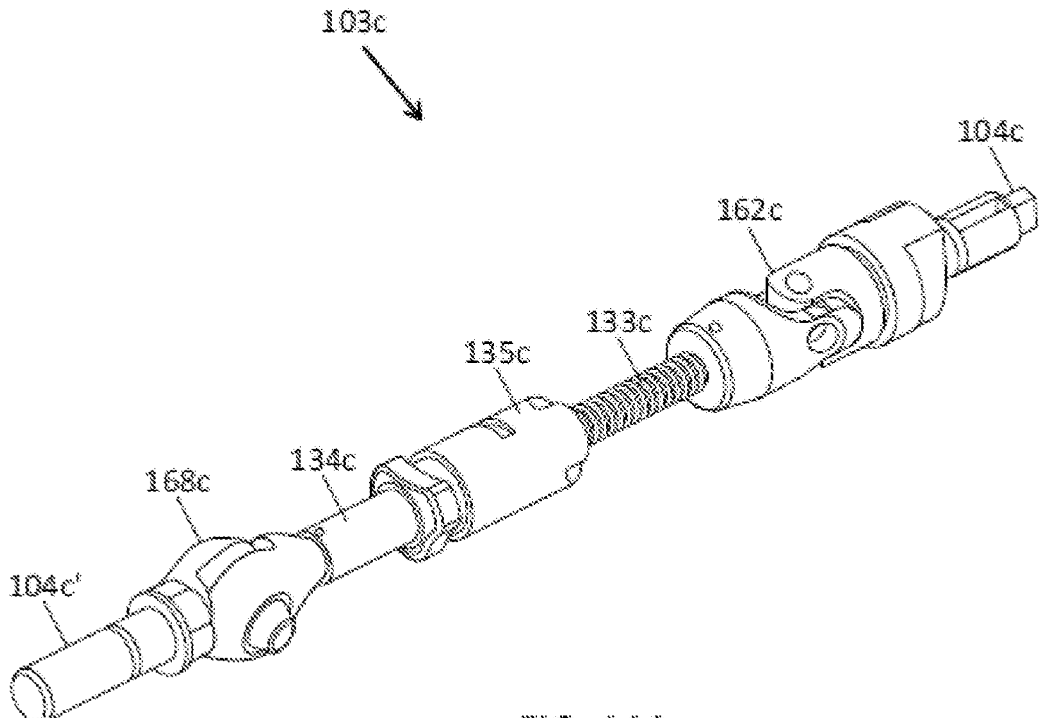

FIG. 14A

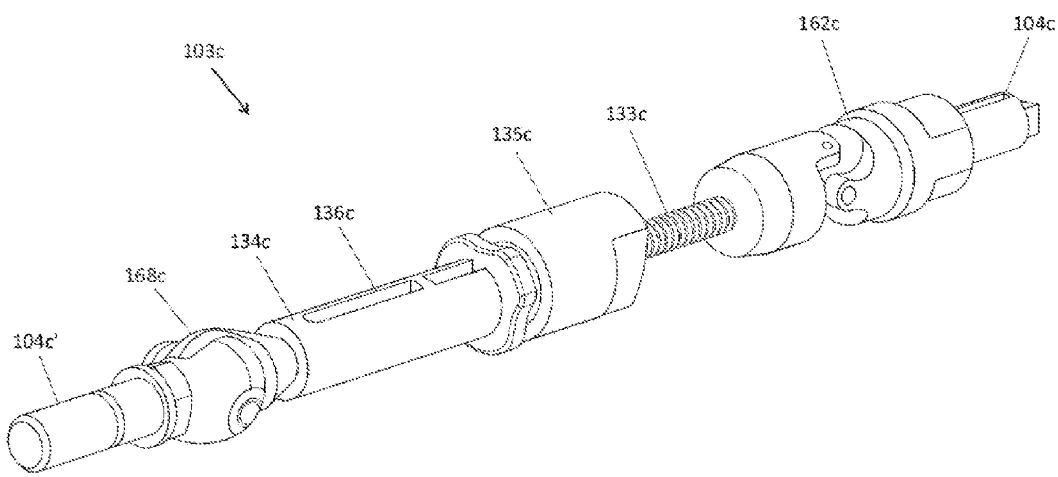

FIG. 14B

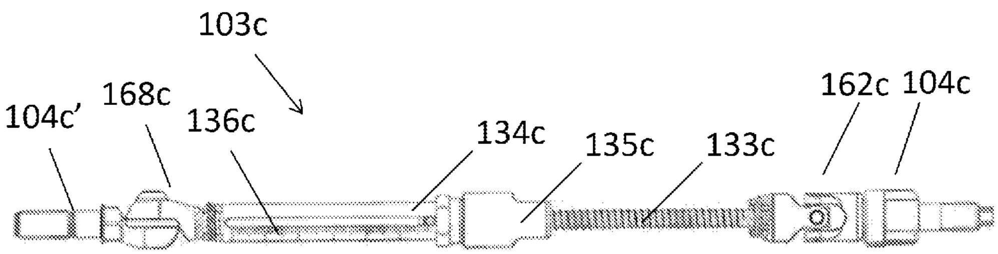

FIG. 14C

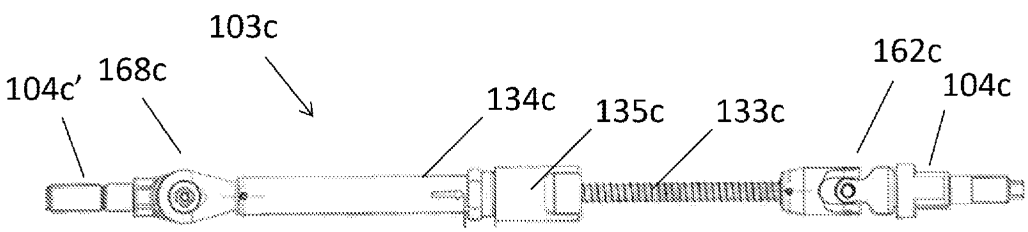

FIG. 14D

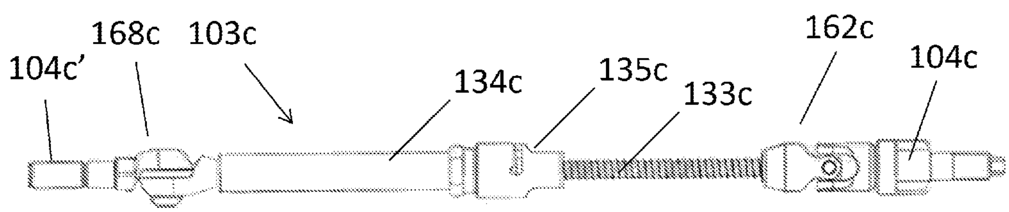

FIG. 14E

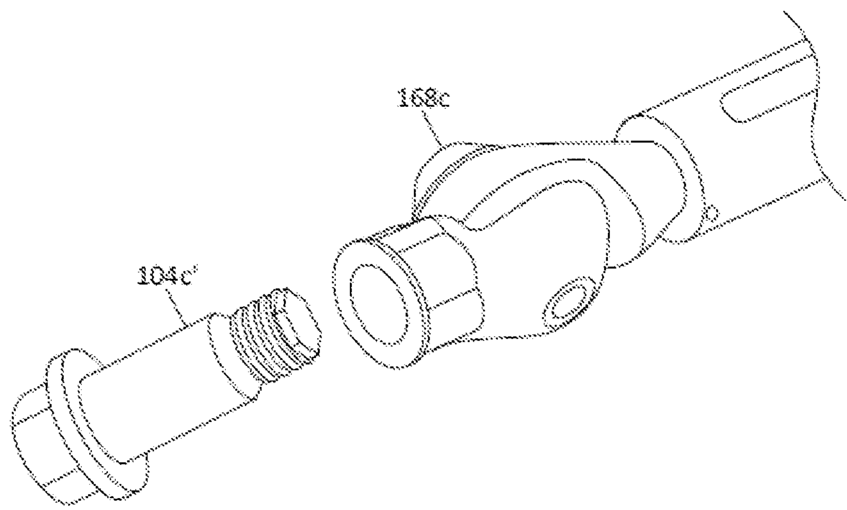

FIG. 14F

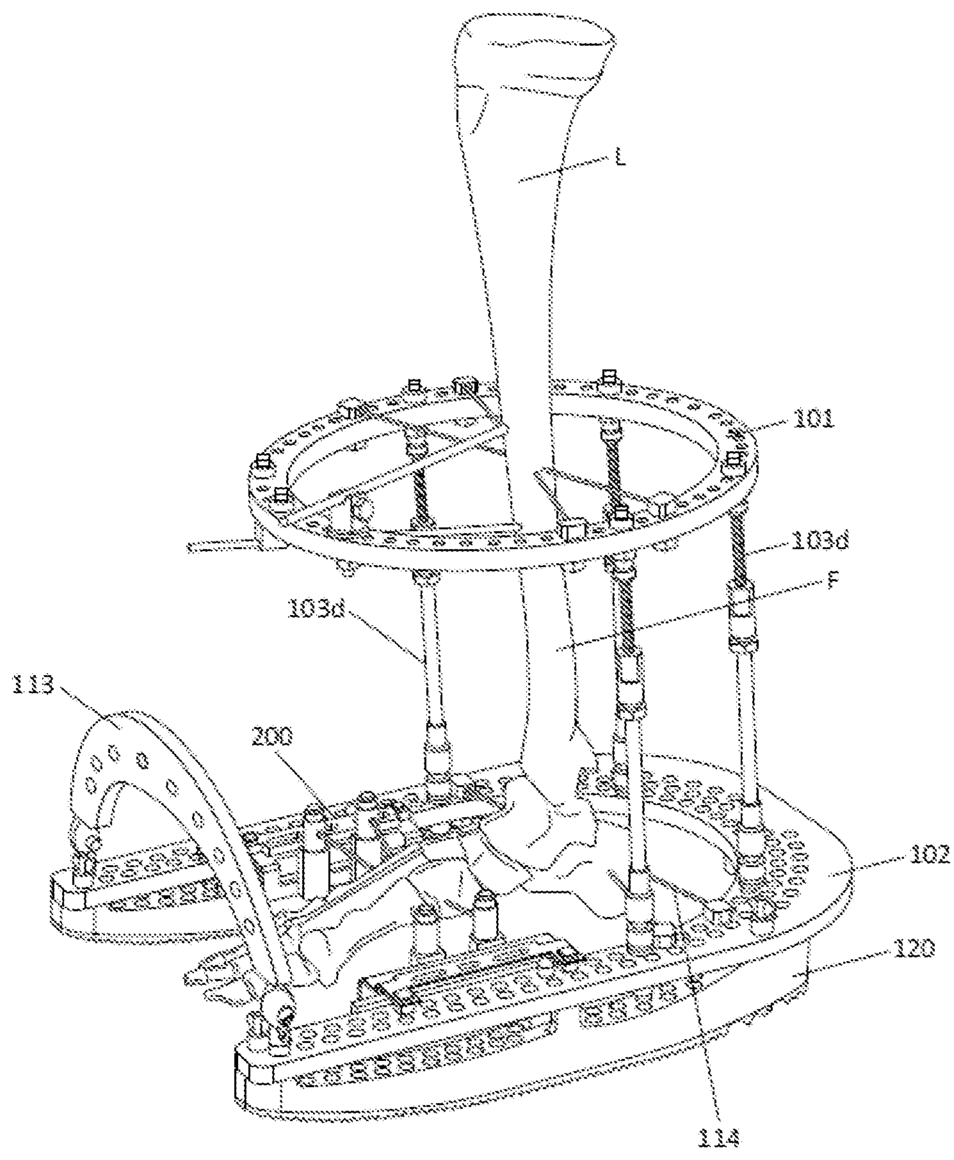

FIG. 15

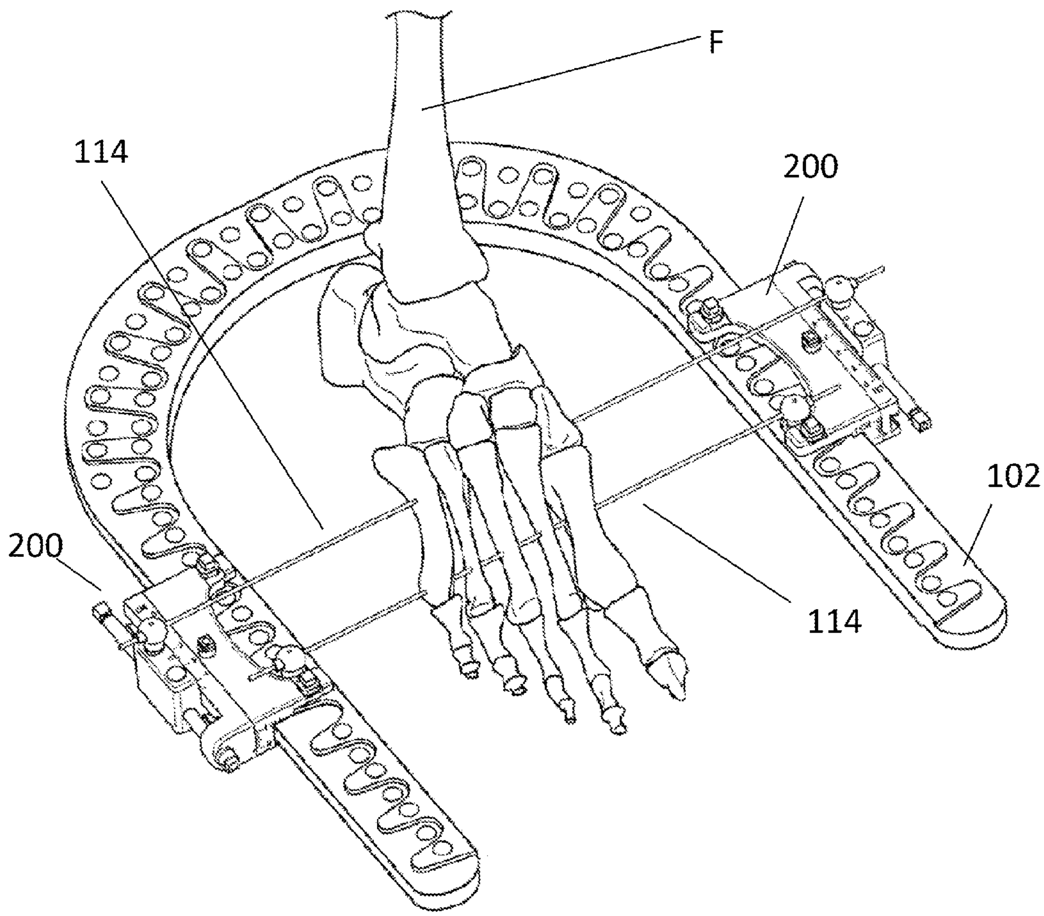

FIG. 16

EXTERNAL FIXATOR SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. patent application Ser. No. 13/792,634, filed Mar. 11, 2013, which application is a continuation-in-part of U.S. Pat. No. 8,834,467, filed Aug. 9, 2011, which patent is related to European Application No. 10 172 523.2, filed Aug. 11, 2010, and European Application No. 11 176 512.9, filed Aug. 4, 2011. The disclosures of each of the above referenced applications are hereby incorporated by reference herein in their entireties.

FIELD OF THE INVENTION

The present disclosure relates to an external fixation frame for correcting a bone deformity. More particularly, the present disclosure relates to an external fixation frame having an arch or half-ring connected to a bottom fixation ring of the external fixation frame.

BACKGROUND OF THE INVENTION

Many different types of bone deformities can be corrected using external fixation systems to perform the distraction osteogenesis process. For example, an Ilizarov device or similar external fixation system may be used. Such systems generally use rings also designated as fixation plates connected by threaded rods or struts with nuts for manipulation, angulation, and translation of the length discrepancies of bones. The nuts that are used to adjust the length of the struts are generally manually adjusted by a surgeon or by the patient with a wrench or by hand to change the positions of the rings and/or percutaneous fixation components.

As the position adjustments of the components are made where the nuts are secured, it can be difficult for the patient, for example, to make the required daily adjustments with consideration of maintaining stable fixation. Other devices use different techniques to adjust the effective length of the struts or rods but all must be adjusted somewhere between the ends thereof. The devices generally offer limited access for the patient. Because the adjustments are often a daily task for the patient, easier access to the frame adjustment points would be a significant advantage.

Fixation systems, especially foot fixation systems, have many areas of needed improvement. For example, existing foot fixation products on the market are static and do not allow for adjustment and pivoting. Certain foot fixation systems include a solid and stationary half-ring assembled to the foot ring. This lack of flexibility and motion restricts the motion of the foot and ankle and the external fixation frame during deformity correction, making the process more difficult for the physician and the patient and potentially preventing an optimal clinical outcome.

To allow for deformity correction of the foot and ankle, an adjustable and pivoting component that can be assembled onto the distal portion of a foot ring of an external fixation frame is needed.

BRIEF SUMMARY OF THE INVENTION

In one embodiment, an external fixation frame for correcting a bone deformity includes a first and second fixation ring. A posterior adjustable length strut couples a posterior portion of the first fixation ring to a posterior portion of the second fixation ring, the posterior adjustable length strut including a

universal joint at an end thereof. Medial and lateral adjustable length struts couple medial and lateral portions of the first fixation ring to medial and lateral portions of the second fixation ring, respectively. The medial and lateral adjustable length struts include a constrained hinge joint at ends thereof. A half ring is hingedly coupled to the second fixation ring and an anterior adjustable length strut couples an anterior portion of the first fixation ring to the half ring.

The half ring may include a lateral end potion, a medial end portion, and an arcuate body portion connecting the lateral end portion to the medial end portion. The medial end portion of the half ring includes a first constrained hinge joint and the lateral end portion of the half ring includes a second constrained hinge joint. The second fixation ring may be U-shaped and include a medial anterior projection, a lateral anterior projection, and a rounded posterior section connecting the medial anterior projection to the lateral anterior projection. The first constrained hinge joint may couple the medial end portion of the half ring to the medial anterior projection of the second fixation ring and the second constrained hinge joint may couple the lateral end portion of the half ring to the lateral anterior projection of the second fixation ring.

The anterior adjustable length strut may include a distal constrained hinge joint and a proximal universal hinge joint. The distal constrained hinge joint of the anterior adjustable length strut may be coupled to the arcuate body portion of the half ring and the proximal universal hinge joint of the anterior adjustable length strut may be coupled to the anterior portion of the first fixation ring. The medial adjustable length strut and lateral adjustable length strut may each include an aperture proximal of the constrained hinge joint, each aperture being configured to accept a wire fastener therethrough. The half ring may include an aperture with a diameter and the anterior adjustable length strut may include a connecting element at a distal end thereof. The connecting element may include internal threading on the distal end of the strut and an externally threaded bolt, a portion of the bolt having a diameter greater than the diameter of the half ring aperture.

The external fixation frame may also include a rocker member coupled to a bottom surface of the second fixation ring. The rocker member may include a curved body portion with at least one connecting element projecting proximally from the curved body portion and configured to mate with an aperture in the second fixation ring. The connecting element may include a main body portion extending through an aperture in the curved body portion of the rocker member and a distal flange. The distal flange may extend distally of the main portion and be configured to contact a corresponding shoulder portion of the aperture in the curved body portion. The rocker member may further include a ground-contacting rounded distal portion coupled to a distal portion of the curved body portion of the rocker member, the ground-contacting rounded distal portion having a textured ground-contacting surface.

In another embodiment, an external fixation frame for correcting a bone deformity may include a first and second fixation ring. The second fixation ring may have a first free end, a second free end, and an arcuate portion connecting the first free end to the second free end. At least four struts couple the first fixation ring to the second fixation ring. At least one bone fastener has a first end operably coupled to the first free end of the second fixation ring and a second end operably coupled to the second free end of the second fixation ring. A half ring has a first free end, a second free end, and an arcuate portion connecting the first free end to the second free end. The first free end of the half ring is coupled to the first free end of the second fixation ring and the second free end of the half ring is coupled to the second free end of the second fixation ring. The bone fastener may be a K-wire. The external fixation frame may also include a first compression module coupled to the first free end of the second fixation ring and a second compression module coupled to the second free end of the second fixation ring. The first end of the bone fastener may be coupled to the first compression module and the second end of the bone fastener may be coupled to the second compression module.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention are described in the following with reference to the drawings, which are for the purpose of illustrating the present preferred embodiments of the invention and not for the purpose of limiting the same.

A more complete appreciation of the subject matter of the present invention and the various advantages thereof can be realized by reference to the following detailed description in which reference is made to the accompanying drawings in which:

FIGS. **1**A-C show side views of different strut configurations of an external fixator system of the present invention with first and second plates coupled to a tibia and a foot of a patient respectively;

FIG. **2** shows an embodiment of an actuation unit of the present invention used in the external fixator system of FIGS. **1**A-C;

FIG. **3** shows a cross-sectional view of the actuation unit of FIG. **2**;

FIG. **4** shows a perspective partial cross-sectional view of the actuation unit of FIG. **3**;

FIG. **5** shows the actuation unit of the previous figures in connection with an adjustable length strut to be used to connect two rings of the external fixator with each other; and

FIG. **6** shows a detailed view of FIG. **5**.

FIG. **7** shows a perspective view of an external fixation frame according to another embodiment of the invention.

FIG. **8**A shows a front plan view of a half-ring of the external fixation frame shown in FIG. **7**.

FIG. **8**B shows a perspective view of the half-ring of FIG. **8**A.

FIG. **8**C shows a partial cross-sectional view of the half-ring of FIG. **8**A.

FIGS. **9**A-B show top plan views of a bottom fixation ring of the external fixation frame shown in FIG. **7**.

FIG. **10**A shows a perspective view of a rocker shoe of the external fixation frame shown in FIG. **7**.

FIGS. **10**B-D shows various plan views of the rocker shoe of FIG. **10**A.

FIG. **10**E shows an exploded view of the components of the rocker shoe of FIG. **10**A.

FIG. **10**F shows a perspective view of the rocker shoe of FIG. **10**E.

FIG. **11**A shows a perspective view of a universal hinge strut of the external fixation frame shown in FIG. **7**.

FIGS. **11**B-D show various plan views of the universal hinge strut shown in FIG. **11**A.

FIG. **12**A shows a perspective view of a constrained hinge strut of the external fixation frame shown in FIG. **7**.

FIGS. **12**B-D show various plan views of the constrained hinge strut shown in FIG. **12**A.

FIGS. **13**A-D show various views of a constrained hinge joint of the constrained hinge strut shown in FIGS. **12**A-D.

FIG. **14**A shows a perspective view of one embodiment of a half-ring strut of the external fixation frame shown in FIG. **7**.

FIG. **14**B shows a perspective view of another embodiment of a half-ring strut of the external fixation frame shown in FIG. **7**.

FIGS. **14**C-E show various plan views of the half-ring strut shown in FIG. **14**B.

FIG. **14**F shows an enlarged perspective partial view of a connecting element of the half-ring strut shown in FIGS. **14**B-E.

FIG. **15** is a perspective view of an alternate embodiment of an external fixator system.

FIG. **16** is a perspective view of the bottom fixation ring and compression modules of the external fixator system of FIG. **15**.

DETAILED DESCRIPTION

As used herein, the term "proximal" means a direction closer to the heart of a patient and the term "distal" means a direction farther away from the heart of a patient. The term "anterior" means towards the front part of the body or the face and the term "posterior" means towards the back of the body. The term "medial" means toward the midline of the body and the term "lateral" means away from the midline of the body.

Referring to FIGS. **1**-**6**, there is shown an embodiment of an external fixator system of the present invention. As shown in those figures, the external fixator system includes first and second fixation plates **1**, **2** coupled to first and second bone segments L, F respectively, a plurality of adjustable length struts **3**, at least one actuation unit **4**, and a plurality of clamping units **4'**.

FIGS. **1**A-E show an exemplary embodiment of an external fixator system. The external fixator system comprises at least two fixation plates **1**, **2** which are arranged at a distance to each other and at least one adjustable length strut **3** which is in connection with the fixation plates **1**, **2**. Such struts are shown in U.S. Publications 200910198234 and 200910198235 the disclosures of which are incorporated herein by reference in their entirety. Fixation plates **1**, **2** serve as bearing elements for pins which are in connection with bony structure such as first and second bone segments L, F, for example. The orientation as well as the distance between two fixation plates **1**, **2** thereby define the orientation and distance between fractured elements of the bony structure. Each of the fixation plates **1**, **2** comprises a front surface **12** which extends over the largest dimension of the plate **1**, **2**.

In the present embodiment there is an upper fixation plate **1** in connection with the lower leg L and a lower fixation plate **2** in connection with the foot F. The lower fixation plate **2** comprises also a rolling structure **20** to enable a user to walk around.

Adjustable length struts **3** each include a length adjusting mechanism **32** having a threaded strut **33** and a non-rotating strut **34** having an internal thread along at least a portion of a length thereof in which the threaded strut **33** engages. Struts **3** include a first end region **30** and a second end region **31** in which the struts **3** are coupled to the respective fixation plates. In the present embodiment the struts **3** are connected to the upper fixation plate **1** by means of an actuation unit **4** and to the lower fixation plate **2** by means of a clamping element **4'**. It is also possible to use an actuation unit **4** to connect the strut **3** to the upper fixation plate **1** as well as to the lower fixation plate **2**. The actuation unit **4** is preferably provided to actuate the length-adjusting strut in order to adjust its length.

The actuation unit **4** is preferably in a fixed connection with fixation plates **1**, **2** as shown in FIGS. **1**A-E. The term fixed connection is to be understood as being a connection which prevents unintentional relative motion between the actuation unit **4** and fixation plates **1**, **2**. In particular, a rotational motion is preferably prevented. Preferably, fixation plates **1**, **2** comprise a plurality of openings **10** in which such actuation units **4** can be arranged and such that the fixed connection can be established. The fixed connection has the advantage such that the device can be adjusted easily without the aid of several tools.

FIG. **2** shows the actuation unit **4** in a perspective view and FIGS. **3** and **4** show sectional views. The actuation unit **4** comprises an outer sleeve **5** in which an actuation element **6** is arranged. The actuation unit **4** is in connection with the fixation plate **1**, **2** by means of the outer sleeve **5**. Outer sleeve **5** is shown having a partly round configuration but may have other configurations such as rectangular, spherical, square and the like.

The outer sleeve **5** extends along a middle axis M as shown in FIG. **3** and comprises a through opening **50**, a clamping section **51** and a bearing section **52**. The clamping section **51** includes a threaded section **53** and a shaft section **54**. The threaded section is in contact with a nut **56** which is used to secure the outer sleeve **5** to the fixation plate **1**, **2**. On the outer side a flange **55** divides the clamping section **51** from the bearing section **52**. The bearing section **52** has mainly two purposes, namely to bear the actuation element and to provide a bearing of the outer sleeve **5** in the opening **10**. Hence the inner side provided by said through opening **50** serves to provide a bearing for an actuation element **6** of actuation unit **4**. The outer side of the bearing section **52** serves mainly to provide a bearing for the outer sleeve **5** within said opening **10** in the ring **1** as explained below with regard to FIG. **3** in more detail. The outer side of the bearing section **52** has in the present embodiment a rectangular cross section with rounded edges **57** and flat sidewalls **58**. Edges **57** and sidewalls **58** extend parallel to the middle axis M. The part which is located in vicinity of flange **55**, however, is preferably also in connection with the opening in the fixation plate **1**, **2**.

In FIG. **3**, one embodiment of an opening **10** in the fixation plate **1**, **2** is schematically shown. The opening **10** comprises a shoulder **11** which subdivides the opening **10**. The opening **10** comprises a first section **13** and a second section **14**. The shoulder **11** is located between the first section **13** and the second section **14**. The first section **13** of the opening **10** has therefore a complementary or corresponding shape as the shaft section **54**. In the present embodiment shaft section **54** as well as first section **13** have circular cross-sections and the second section **14** as well as the bearing section **52** have a rectangular cross-section.

When the outer sleeve **5** is inserted into the opening **10** the shoulder **11** is preferably in contact with flange **55**. The shaft section **54** of the outer sleeve **5** extends through the first section **13** of the opening **10** and the bearing section **52** extends into the section **14**. The outer sleeve **5** is fixed to the fixation plate **1**, **2** by means of nut **56** which retracts the outer sleeve **55** relative to fixation plate **1**, **2** such that flange **55** comes in contact with the shoulder **11**.

From FIG. **2** it becomes evident that the cross-section of the outer surface of the bearing section **52** which is in contact with the opening **10** is provided such that rotation of outer sleeve **5** relative to the fixation plate **1**, **2** is prevented. For that reason the opening **10** has a complementary shape. In the present embodiment, the outer sleeve **5** has partly a rectangular cross-section with rounded edges. Here the rectangular cross-section is mainly provided by the outer side of the bearing section **52** or the outer surfaces of the bearing section **52**, respectively.

The actuation element **6** of actuation unit **4** preferably extends along the middle axis M and comprises mainly a shaft section **60** which extends through the opening **50** of the outer sleeve and a connection section **61** which is in connection with strut **3**. The actuation element **6** can be actuated, i.e. rotated, by means of a tool **67** shown in FIG. **5**, which preferably engages in a socket **66** of the actuation element **6**. Socket **66** is thereby arranged such that the tool can be introduced in a direction which is more or less in line with the axis of the strut or in a direction perpendicular to the fixation plate **1**, **2** in particular to surface **12**. The orientation of the socket **66** has thereby the advantage that easy access is provided from the top of the fixation system and that the length of the struts **3** can be adjusted easily by any user of the system.

The actuation element **6** is borne by means of a ball bearing **9** in the outer sleeve **5**. In the present embodiment, the ball bearing **9** is provided by means of the shaft section **61** and the bearing section **52**. A separate ball bearing is also possible, but a ball bearing which is provided according to the embodiment of FIG. **3** is preferably compact in terms of size.

As shown in FIG. **3**, the bearing section **52** and the shaft section **61** preferably comprise respective grooves **90**, **91** in which a plurality of balls **92** are arranged. Groove **90** extends into the surface of the opening **50** and encompasses the whole opening **50**, whereas groove **91** is arranged in the shaft **61** of the actuation element **6**. The grooves **90**, **91** provide a channel in which the balls **92** are arranged. Balls **92** may be introduced into the channel via an opening **93** in the shaft section **61** which is covered by means of a cover **94**.

Between the outer sleeve **5** and the actuation element **6** there is arranged a feedback unit **7** as shown in FIGS. **3** and **4**. In the present embodiment, the feedback unit **7** is provided by means of a spring-loaded ball **70** and corresponding chambers **71**. The spring-loaded ball **70** is arranged in an opening **72** in the actuation element **6**. Between the ground of the opening **72** and the spring-loaded ball **70** there is arranged a spring **73** which provides a force that pushes the ball **70** into a respective chamber **71**. The chambers **71** are arranged in the surface of the through opening **50** in the outer sleeve **5**. Upon rotation of the actuation element **6** relative to the outer sleeve **5**, the spring-loaded ball **70** is pushed against the spring force by means of the transition portion **74** between two neighboring chambers **71**. As soon as the next chamber **71** is in line with the spring axis, the spring-loaded ball **70** will be moved into the respective chamber **71**. This mechanism results in a clicking noise which provides the user with a respective audible feedback about the amount of actuation that is being made.

There are a plurality of chambers **71** arranged which are preferably distributed evenly around the perimeter of the through opening **50** of the outer sleeve **5**. In the present embodiment, eight chambers **71** are arranged such that each chamber is located approximately 45° from a neighboring chamber, but it is also possible to arrange more or less than eight chambers. The number of chambers preferably depends on the application. Preferably, each time the actuation element is rotated such that the spring-loaded ball moves from one chamber **71** and into a neighboring chamber **71**, adjustable length strut is lengthened 1 mm. Each time the actuation element is rotated such that the spring-loaded ball moves from one chamber **71** and into a neighboring chamber **71**, adjustable length strut may be lengthened between 0.1 mm to 1 mm.

It is important for the adjustable length strut to not be lengthened so easily or inadvertently such that accidental injury may be caused. Osteogenesis generally occurs over a considerable length of time and lengthening and/or angulation adjustment between adjacent bone fragments should only be done in a prescribed manner. Therefore, chambers **71** are preferably deep enough to securedly house at least a portion of the spring loaded ball **70** and a spring constant k of the spring is sufficient enough to force the ball against side walls in the respective chambers such that preferably only intended actuation of the actuation unit causes the actuation unit to actuate.

With regard to the embodiment as shown in FIGS. **3** and **4**, opening **72** can also be arranged in the outer sleeve **5** and that the chambers **71** can also be arranged in the actuation element **6**. With such a configuration a same or similar result can preferably be achieved.

The strut **3** with its end region is in a fixed connection with the actuation element **6**. In the present embodiment, there is a Cardan (universal) joint **62** arranged between the strut **3** and the actuation element **6** in order to compensate angular differences between the strut **3** and the actuation element **6**. Furthermore the actuation element **6** comprises an opening **63** in which the strut **3** extends as shown in FIG. **6**. Preferably the strut **3** is in connection with the opening **63** by means of a thread, a press fit or any other suitable connection method which prevents a relative movement between the strut **3** and the actuation element **6**. In case a thread is used, it is advantageous to secure the thread by means of a pin **64** which extends through the opening **63** and the strut **3**. For that reason a pin opening **65** is arranged in the region of the opening **63**. The use of a Cardan joint **62** has the advantage that adjustments can be made in advantageous manner, namely in a preferably precise and smooth manner.

Upon rotation of the actuation element **6**, the strut will also be rotated and its length will be adjusted according to the degree of rotation. The feedback unit **7** then provides the user with an acoustic as well as with a haptic feedback due to its mechanical structure as outlined above.

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The arrangement of the feedback unit **7** as mentioned herein has the advantage that in terms of dimension a very compact structure can be achieved. Thereby the overall weight can be significantly reduced and it is preferably more convenient for the patient to use such a structure.

As shown in FIG. **2**, markings **67** showing the direction of rotation are arranged on an outer face of actuation unit **4** in order to allow the user to know in which direction actuation unit **4** is being actuated. In this region it is also possible to arrange a scale on which the user can visually recognize the amount of rotation, whereby a visual feedback can be provided.

FIGS. **5** and **6** show the strut **3** in connection with actuation unit **4** by way of its first end region **31** and with the clamping element **4'** via its second end region **32**. The clamping element **4'** clamps the strut **3** in fixed manner to the fixation plate **1**, **2** which is not shown here. The actuation unit **4** is also in a fixed connection with the respective fixation plate, but the actuation element **6** which is arranged within the actuation unit **4** is rotatable relative to the actuation unit **4**. A rotation of the actuation element **6** preferably results in a rotation of the threaded strut **33** and in connection with the non-rotating strut section **34** such that the length of the strut **3** will be adjusted.

FIG. **7** illustrates a perspective view an embodiment of an external fixator similar to that illustrated in FIGS. **1**A-C. Similar parts are generally identified by a number **100** greater than the corresponding part identified in FIGS. **1**A-C. FIG. **7** particularly illustrates a half-ring **113** hingedly coupled to the bottom fixation ring **102** and coupled to the top fixation ring **101** via half-ring strut **103***c*. Although the term half-ring is used, it should be understood that the half-ring is not limited to being half of a circular ring, but may take other shapes, preferably generally arcuate shapes. The top fixation ring **101** is further connected to the bottom fixation ring **102** with constrained hinge struts **103***b* and a universal hinge strut **103***a*.

As illustrated in FIG. **7**, the half-ring **113** is coupled to the anterior part of the bottom fixation ring **102**. Among other benefits, the half-ring **113** closes the open bottom fixation ring **102** such that the open bottom fixation ring does not deflect, or only minimally deflects, when fixation features, such as Kirschner wires ("K-wires") **114** are tensioned. Without half-ring **113**, tensioning a member fixed at opposite ends of the open bottom fixation ring **102**, such as a K-wire **114**, may tend to cause the open portions of bottom fixation ring to deflect closer together. This deflection is limited by the rigid connection of the half-ring **113** to the bottom fixation ring **102**.

The half-ring **113** is best illustrated in FIGS. **8**A-C. The half-ring **113** may include a generally arcuate main portion **1300** similar to a portion of one of the fixation rings **101**, **102**. Similar to the fixation rings **101**, **102**, the half-ring **113** may include a number of openings **1310** to facilitate other members, such as half-ring strut **103***c*, to be attached to the half-ring.

The half-ring **113** may also include hinges **1320** at the ends of the main portion **1300**. The hinges **1320** may include a first hinge portion **1322** and a second hinge portion **1324**. The first hinge portion **1322** may be coupled to the half-ring **113**, for example by an adhesive, or may alternately be integral with the half-ring. As illustrated in FIG. **8**C, the first hinge portion **1322** may include a pronged connecting portion **1323** that mates with recesses in an end of the main portion **1300** of the half-ring **113**. The fit may be a compression fit or a snap fit, or may otherwise be fixed, for example by an adhesive.

The first hinge portion **1322** may also include a textured surface and an aperture to accept a fastener. The aperture preferably is unthreaded. The fastener may be, for example, a screw **1326** with a first portion of the screw shaft unthreaded and a second portion of the screw shaft threaded. The second hinge portion **1324** may be of a generally similar structure to the first hinge portion **1322**, having a textured surface and an aperture to accept a fastener. Preferably, the aperture is internally threaded.

The second hinge portion **1324** may also include a connecting portion **1325**. The connecting portion **1325** may, for example, be cylindrical and configured to pass through an aperture **10** in the bottom fixation ring **2**. The connecting portion **1325** may also be threaded to mate with a locking nut or other fastener to secure the second hinge portion **1324** in a fixed relation to the bottom fixation ring **2**.

The screw **1326** may be inserted through the unthreaded aperture in the first hinge portion. Preferably the unthreaded aperture is large enough that the shaft of the screw **1326** can move freely through the aperture. The threaded portion of the screw **1326** is then inserted through the threaded aperture in the second hinge portion **1324**. The threaded aperture is preferably dimensioned such that the screw **1326** must be rotated to pass through the threaded aperture. As the screw **1326** is rotated, the second hinge portion **1324** is drawn toward the first hinge portion **1322**. When fully inserted, the unthreaded portion of the screw **1326** generally is located at the unthreaded aperture of the first hinge portion **1322** and the threaded portion of the screw is engaged with the threaded aperture of the second hinge portion **1324**. In this position, the first hinge portion **1322** and second hinge portion **1324** are frictionally engaged such that rotation of the first hinge portion relative to the second hinge portion about the screw **1326** is resisted. In the embodiment in which one or both of the hinge portions **1322**, **1324** include textured surfaces, such as ridges, the engagement of the textured surfaces may provide additional resistance against rotation. A nut may also be threaded onto any portion of the screw **1326** that extends beyond the aperture in the second hinge portion **1324** to help prevent unintentional rotation of the screw **1326** when in the fully threaded, locked position.

The bottom fixation ring **102** is illustrated in FIGS. **9**A-B. The bottom fixation ring **102**, in the particular embodiment shown, is generally "U" shaped with a posterior base **1020** and anterior projections **1022**. The bottom fixation ring **102** may include a number of apertures or openings **1024** extending along the length of the bottom fixation ring. Although one particular pattern of openings **1024** is illustrated in FIG. **9**, the number and placement of the openings **1024** is largely a matter of design choice. The openings **1024** may be used to connect components to the bottom fixation ring **102**, such as a variety of struts and compression modules, as is explained in further detail below. Preferably, enough openings **1024** exist such that a surgeon or other user has a variety of choices in the placement of such components.

Rolling structure, or rocker **120**, is illustrated in FIGS. **10**A-F. Generally, rocker **120** has an elongate main body **1200** and an elongate ground-contacting rounded portion **1201**. The ground-contacting rounded portion **1201** may include treads or other surface texture to increase friction with the ground. The ground-contacting rounded portion **1201** may be integral with the main body **1200**, or may be otherwise coupled to the main body, for example by adhesive. The main body and ground-contacting rounded portion may include openings **1202** and **1203**, respectively.

The main body **1200** of the rocker **120** may include one or more connecting pins **1205** (three connecting pins illustrated in FIGS. **10**A and **10**E-F, two connecting pins illustrated in FIGS. **10**B-D). As best illustrated in FIG. **10**B, the connecting pins **1205** may be generally cylindrical and dimensioned to securedly fit within an opening **1202** of the main body **1200**. The bottom of the connecting pins **1205** may include a flange **1206** larger than the diameter of the opening **1202**, such that the connecting pins **1205** cannot be pulled proximally through the rocker **120**. A recess **1207** may be formed on a distal end of the main body **1200** where each connecting pin **1205** is located. The recess **1207** is formed such that the flange **1206** of the connecting pin **1205** is situated distal to the main body **1200** and proximal to the ground-contacting rounded portion **1201** of the rocker **120**. The distal end of the connecting pins **1205** may be threaded and configured to fit through openings **1024** of the bottom fixation ring **102** to secure the rocker **120** to the bottom fixation ring. The distal end of the connecting pins **1205** may be threaded to accept a locking nut **1208** to lock the rocker **120** to the bottom fixation ring **102**.

Although only one rocker **120** is illustrated in FIGS. **10**A-F, it should be understood that two rockers would be used with the bottom fixation ring **102** to provide stable contact with the ground. Also, the rockers **120** may be identical, or may be similarly or symmetrically shaped. For example, as seen in FIG. **10**D, the rocker **120** may include contours, which contours may be mirrored in a second rocker that is used with the bottom fixation ring.

As discussed above, multiple struts may be used to connect components of the fixation system and to allow for various types of movement and positioning between the components. In the illustrated embodiment, at least three different types of struts are used, including universal hinge struts **103***a*, constrained hinge struts **103***b* and half-ring struts **103***c*.

Now referring to FIGS. **11**A-D, universal hinge strut **103***a* may be similar to the adjustable length strut **3** described above. In one embodiment, universal hinge strut **103***a* includes a length adjusting mechanism having a threaded strut **133***a* and a non-rotating strut **134***a* having an internal thread along at least a portion of a length thereof in which the threaded strut **133***a* engages. Universal hinge struts **103***a* may be connected to the upper fixation plate **101** by means of an actuation unit **104***a* and to the lower fixation plate **102** by means of a connecting element **104***a*'. It is also possible to use an actuation unit **104***a* to connect the universal hinge strut **103***a* to the upper fixation plate **101** as well as to the lower fixation plate **102**. The actuation unit **104***a* is preferably provided to actuate the length-adjusting strut in order to adjust its length.

The actuation unit **104***a* may be substantially similar to the actuation unit **4** described above, including a ball and spring mechanism to provide auditory and/or tactile feedback. In the illustrated embodiment, universal hinge strut **103***a* includes a universal joint **162***a* near the connecting element **104***a*'. This is in contrast to the strut **3** described above, in which the universal joint **62** is positioned closer to the actuation element **4**. The internal mechanisms described with relation to strut **3**, however, generally apply with equal force to the universal hinge strut **103***a*. The universal hinge strut **103***a* may also include a quick-release mechanism **135***a*. Generally, the quick-release mechanism **135***a* has a locked position and an unlocked position. In the locked position, the threaded strut **133***a* can move into or out of the non-rotating strut **134***a* only by rotation of the threaded strut into the non-rotating strut. In the unlocked position, the threaded strut **133***a* may be moved into or out of the non-rotating strut **134***a* without rotation of the threaded strut, such that a user may quickly move the threaded strut into the non-rotating strut. This mechanism is more fully described in U.S. patent application Ser. No. 13/592,832, titled "Bone Transport External Fixation Frame."

Now referring to FIGS. **12**A-D, constrained hinge struts **103***b* are nearly identical to universal hinge struts **103***a*, with a constrained hinge joint **168** rather than a universal hinge joint **162**. The constrained hinge joints **168** allow for constrained rotation using a similar or identical mechanism as hinges **1320** of the half-ring **113**. Similar to the universal hinge strut **103***a*, constrained hinge strut **103***b* includes a length adjusting mechanism having a threaded strut **133***b* and a non-rotating strut **134***b* having an internal thread along at least a portion of a length thereof in which the threaded strut **133***b* engages. Constrained hinge struts **103***b* may be connected to the upper fixation plate **101** by means of an actuation unit **104***b* and to the lower fixation plate **102** by means of a connecting element **104***b*'. It is also possible to use an actuation unit **104***b* to connect the constrained hinge strut **103***b* to the upper fixation plate **101** as well as to the lower fixation plate **102**. The actuation unit **104***b* is preferably provided to actuate the length-adjusting strut in order to adjust its length.

The actuation unit **104***b* may be substantially similar to the actuation unit **4** described above, including a ball and spring mechanism to provide auditory and/or tactile feedback. In the illustrated embodiment, constrained hinge strut **103***b* includes a constrained joint **168***b* near the connecting element **104***b*'. The constrained hinge strut **103***b* may also include a quick-release mechanism **135***b*.

Constrained hinge joint **168** is shown in more detail in FIGS. **13**A-D. The constrained hinge joint **168** may include a first hinge portion **1422** and a second hinge portion **1424**. The first hinge portion **1422** may be coupled to non-rotating strut **134***b*. The second hinge portion **1424** may be coupled to the connecting portion **104***b'*.

The first hinge portion **1422** may also include a textured surface and an aperture to accept a fastener. The aperture preferably is unthreaded. The fastener may be, for example, a screw **1426** with a first portion of the screw shaft unthreaded and a second portion of the screw shaft threaded. The second hinge portion **1424** may be of a generally similar structure to the first hinge portion **1422**, having a textured surface and an aperture to accept a fastener. Preferably, the aperture is internally threaded.

The screw **1426** may be inserted through the unthreaded aperture in the first hinge portion. Preferably the unthreaded aperture is large enough that the shaft of the screw **1426** can move freely through the aperture. The threaded portion of the screw **1426** is then inserted through the threaded aperture in the second hinge portion **1424**. The threaded aperture is preferably dimensioned such that the screw **1426** must be rotated to pass through the threaded aperture. As the screw **1426** is rotated, the second hinge portion **1424** is drawn toward the first hinge portion **1422**. When fully inserted, the unthreaded portion of the screw **1426** generally is located at the unthreaded aperture of the first hinge portion **1422** and the threaded portion of the screw is engaged with the threaded aperture of the second hinge portion **1424**. In this position, the first hinge portion **1422** and second hinge portion **1424** are frictionally engaged such that rotation of the first hinge portion relative to the second hinge portion about the screw **1426** is resisted. In the embodiment in which one or both of the hinge portions **1422**, **1424** include textured surfaces, such as ridges, the engagement of the textured surfaces may provide additional resistance against rotation. A nut may also be threaded onto any portion of the screw **1426** that extends beyond the aperture in the second hinge portion **1424** to help prevent unintentional rotation of the screw **1426** when in the fully threaded, locked position.

The constrained hinge strut **103***b* may also include an aperture **169***b*. The aperture **169***b* accepts a K-wire or other bone fastener that travels into the bone. The connection of the K-wire with the bone and the aperture **169***b* of the constrained hinge strut **103***b* lines the axis of the constrained hinge joint **168***b* with the anatomic joint axis.

Now referring back to FIG. **12**C, in one embodiment, constrained hinge joint **168***b* is removably attached to non-rotating strut **134***b* by connection mechanism **199**. Connection mechanism **199** may take any suitable form, such as a pin inserted through apertures, mating threads, snap fitting, press fitting, etc. In this embodiment, the particular joint, in this case a constrained hinge joint **168***b*, may be removed and replaced with a different type of joint, such as a universal hinge joint, polyaxial joint, or otherwise, depending on the particular requirement or desire. This interchangeability allows, for example, a less complex process if a user desires to change the way in which a particular strut is capable of moving.

Now referring to FIG. **14**A, half-ring strut **103***c* is illustrated. Half-ring strut **103***c* is substantially similar to universal hinge strut **103***a* and constrained hinge strut **103***b*, but includes both a universal joint **162***c* and a constrained joint **168***c*. The half-ring strut **103***c* may be used to fix upper fixation ring **101** to half-ring **113**.

Half-ring strut **103***c* includes a length adjusting mechanism having a threaded strut **133***c* and a non-rotating strut **134***c* having an internal thread along at least a portion of a length thereof in which the threaded strut **133***c* engages. Half-ring strut **103***c* may be connected to the upper fixation plate **101** by means of an actuation unit **104***c* and to the half-ring **113** by means of a connecting element **104***c*'. The actuation unit **104***c* is preferably provided to actuate the length-adjusting strut in order to adjust its length.

The actuation unit **104***c* may be substantially similar to the actuation unit **4** described above, including a ball and spring mechanism to provide auditory and/or tactile feedback. In the illustrated embodiment, half-ring strut **103***c* includes a constrained **168***c* near the connecting element **104***c*' and a universal joint **162***c* near the actuation unit **104***c*. The half-ring strut **103***c* may also include a quick-release mechanism **135***c*.

A similar embodiment of half-ring strut **103***c* is illustrated in FIGS. **14**B-E, which also includes a scale **136***c* on the non-rotating strut **134***c*. The scale **136***c* includes indicia along a slot, the slot allowing a user to visualize how far the threaded strut **133***c* has advanced into the non-rotating strut **134***c*.

FIG. **14**F illustrates an enlarged view of the connecting element **104***c*' of the half-ring strut **103***c*. In the illustrated embodiment, the connecting element **104***c*' is bolt with external threading that mates with internal threading in a portion of the constrained joint **168***c*. The bolt includes a portion with a diameter larger than the diameter of a corresponding aperture in a fixation element, such as the half-ring **113**. This connection may be accomplished by other mechanisms, for example using an internally threaded nut that threads onto the end of half-ring strut **103***c*. These mechanisms may apply with equal force to the other struts described herein.

In one embodiment of the fixation device, one universal hinge strut **103***a* fixes the top fixation plate **101** to the bottom fixation plate **102** at a posterior side of the device. Two constrained hinge joints **103***b* fix the top fixation plate **101** to the bottom fixation plate **102** at the medial and lateral sides of the device. A half-ring **113** is fixed at the anterior end of the bottom fixation plate **102**, and a half-ring strut **103***c* fixes the half-ring **113** to an anterior portion of the top fixation plate **101**. Each of the struts **103***a-c* may be increased or decreased in length as described above. The universal hinge strut **103***a* allows for top fixation ring **101** to move relative to the bottom fixation ring **102** with rotation about three axes. The constrained hinge strut **103***b* allows for the top fixation ring **101** to move relative to the bottom fixation ring **102** with rotation about a single axis. The half-ring **113** is constrained to rotation about one axis of rotation due to the hinges **1320** connecting the half-ring to the bottom fixation ring **102**. The axis about which the half-ring rotates may be an axis that extends through the center of hinges **1320**. The half-ring strut **103***c* allows the top fixation ring **101** to be rotated about three axes with respect to the half-ring **113**, due to the universal joint **168***c* of the half-ring strut. This configuration allows the half-ring **113** to be assembled in multiple locations and positions on the distal portion of the foot ring, the half-ring having a lockable hinge. The combination of the features above allows for increased control of the foot and ankle in order to properly return it to an anatomic and functional position. The device also limits and/or avoids the possibility of changing of motor struts during treatment. In addition, the half-ring **113** provides added strength to the frame itself, as described above, by bridging the two free ends of the bottom fixation ring **102**.

Now referring to FIG. **15**, another embodiment of a foot fixation frame is illustrated. The illustrated embodiment is a static frame, using the same top and bottom fixation rings **101**, **102** and half-ring strut **113** and rocker **120** as described previously. This embodiment, however, includes a different configuration of struts. Specifically, four or more struts **103***d* connect the top fixation ring **101** to the bottom fixation ring **102**. By using four or more struts **103***d*, the rings **101** and **102** are over constrained and do not change positions relative to one another. As such, the struts **103***d* may be static struts. The struts **103***d* may also be any of those described previously, but kept in a locked position during the deformity correction. For example, a strut capable of polyaxial movement may be used for struts **103***d*. The strut may be angled initially when fixing top fixation ring **101** to bottom fixation ring **102** to provide for correct positioning, and then locked such that the strut **103***d* resists any additional repositioning.

The bottom fixation ring **102** may also include one or more foot compression modules **200**, as illustrated in FIG. **15**. Generally, the foot compression modules **200** are connected to the bottom fixation ring **102** and half pins or wires (e.g. K-wires **114**) extend from a first compression module **200**, through (or into) the foot F, and are fixed on the other side to the bottom fixation ring **102** or a second compression module **200**. These compression modules **200** allow for controlled manipulation of the k-wires **114**, and thus the bone fragments, during the deformity correction process. Compression modules are more fully described in U.S. Patent Publication No. 2011/0082458 and U.S. patent application Ser. No. 13/788,466 filed to Crozet et al., filed Mar. 7, 2013, and titled “Dynamic External Fixator and Methods for Use.” The entire content of each of these applications is hereby incorporated by reference herein. As discussed above, when tensioning the K-wires **114**, using the compression modules **200** or otherwise, the projecting ends of the bottom fixation ring **102** tend to deform because of the applied force and further because of the open shape of the bottom fixation ring. The inclusion of the half-ring **113**, connected in the same way as described above, resists deformation during tensioning of K-wires **114**.

Although the invention herein has been described with reference to particular embodiments, it is to be understood that these embodiments are merely illustrative of the principles and applications of the present invention. It is therefore to be understood that numerous modifications may be made to the illustrative embodiments and that other arrangements may be devised without departing from the spirit and scope of the present invention as defined by the appended claims. For examples, components of one embodiment described herein may be combined with components of another embodiment described herein without departing from the scope of the invention.

The invention claimed is:

1. A strut for coupling a first fixation element to a second fixation element, the strut comprising:
- a first strut portion;
- a second strut portion threadingly coupled to the first strut portion;
- a first joint coupled to an end of the first strut portion and configured to rotatably couple the first strut portion to one of the first and second fixation elements; and
- a coupling mechanism removably coupling the first joint to the end of the first strut portion.

2. The strut of claim **1**, wherein the first joint is selected from the group consisting of a universal hinge joint, a polyaxial joint, and a constrained hinge joint.

3. The strut of claim **1**, wherein the strut includes a second joint coupled to an end of the second strut portion and configured to rotatably couple the second strut portion to the other of the first and second fixation elements.

4. The strut of claim **3**, wherein the second joint is selected from the group consisting of a universal hinge joint, a polyaxial joint, and a constrained hinge joint.

5. The strut of claim **1**, wherein the coupling mechanism is a pin.

6. The strut of claim **5**, wherein the first joint and the end of the first strut portion each include at least one aperture configured to receive the pin.

7. The strut of claim **1**, wherein the coupling mechanism includes a first mating thread and a second mating thread.

8. The strut of claim **7**, wherein the first mating thread is an external thread on the first joint and the second mating thread is an internal thread on the end of the first strut portion.

9. The strut of claim **7**, wherein the first mating thread is an internal thread on the first joint and the second mating thread is an external thread on the end of the first strut portion.

10. The strut of claim **1**, wherein the first joint is configured to snap fit or press fit with the end of the first strut portion.

11. A fixation system kit comprising:
- a first fixation element;
- a second fixation element;
- at least one strut having a first strut portion telescopically coupled to a second strut portion, a first connecting member on the first strut portion configured to couple the first strut portion to the first fixation element,
- at least two joints, each configured to rotatably couple an end of the second strut portion to the second fixation element; and
- at least one coupling mechanism configured to removably couple the joints to the end of the second strut portion.

12. The kit of claim **11**, wherein each joint is selected from the group consisting of a universal hinge joint, a polyaxial joint, and a constrained hinge joint.

13. The kit of claim **11**, wherein the at least one coupling mechanism is a pin.

14. The kit of claim **13**, wherein each joint and the end of the second strut portion include at least one aperture configured to receive the pin.

15. The kit of claim **11**, wherein each joint includes an external thread configured to connect to an internal thread on the end of the second strut portion.

16. The kit of claim **11**, wherein each joint includes an internal thread configured to connect to an external thread on the end of the second strut portion.

17. The kit of claim **11**, wherein each joint is configured to snap fit or press fit with the end of the second strut portion.

18. The kit of claim **11**, wherein a single pin is configured to couple each joint to the end of the second strut portion.

19. The kit of claim **11**, wherein one of the joints is selected from the group consisting of a universal hinge joint, a polyaxial joint, and a constrained hinge joint, and the other the joints is selected from a different member of the group consisting of a universal hinge joint, a polyaxial joint, and a constrained hinge joint.

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